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COST OF CLEAN AIR 1974

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APRIL 1974

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THE COST OF CLEAN AIR

ANNUAL REPORT

OF THE

ADMINISTRATOR
ENVIRONMENTAL PROTECTION AGENCY

TO THE

CONGRESS OF THE UNITED STATES

In Compliance with
Public Law 91-604

APRIL, 1974

1a

PREFACE

This report, the sixth submitted to Congress, complies with Section 312(a) of the Clean Air Act, as amended by Public Law 91-604, the Clean Air Amendments of 1970, and is the fourth prepared under the direction of the Administrator of the Environmental Protection Agency. Section 312(a) reads as follows:

> Sec. 312(a). In order to provide the basis for evaluating programs authorized by this Act and the development of new programs and to furnish the Congress with the information necessary for authorization of appropriations by fiscal years beginning after June 30, 1969, the Administrator, in cooperation with State, interstate, and local air pollution control agencies, shall make a detailed estimate of the cost of carrying out the provisions of this Act; a comprehensive study of the cost of program implementation by affected units of government; and a comprehensive study of the economic impact of air quality standards on the Nation's industries, communities, and other contributing sources of pollution, including sources of pollution, including an analysis of the national requirements for and the cost of controlling emissions to attain such standards of air quality as may be established pursuant to this Act or applicable State law. The Administrator shall submit such detailed estimate and the results of such comprehensive study of cost for the five-year period beginning July 1, 1969, and the results of such studies, to the Congress not later than January 10, 1969, and shall submit a re-evaluation of such estimate and studies annually thereafter.

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I. INTRODUCTION AND SUMMARY

PURPOSE AND SCOPE

Section 312(a) of the Clean Air Act Amendments of 1970 requires an annual report on the prospective costs and impacts of governmental and private efforts to carry out the provisions of the Act. This report is the sixth submitted under the Act.

National cost estimates are presented for governmental programs as well as those for the control of the major sources of air pollution. For this purpose the sources of air pollution are broadly divided into three major categories: transportation sources, industrial sources, and sources related to stationary fossil fuel consumption. Coverage includes not only those pollutants for which national ambient air quality standards have been promulgated, but also pollutants covered by proposed hazardous air-pollutant-emission standards and by new source performance standards.

Estimates of costs, benefits, and impacts reported herein are based, wherever possible, upon actual regulations specified by the states in implementation plans submitted to EPA. All costs in this report are in 1973 dollars.

This report does not presume to include all costs of abating air pollution. Even before the Clean Air Act of 1967, costs were incurred in response to obvious pollution problems and to local legislation. Therefore, the costs herein are estimated incremental costs, over and above any cost of control incurred or the level of control practiced prior to the Act of 1970.

Fiscal year 1971 was judged as the appropriate baseline from which incremental costs are to be assessed. This is in keeping with the passage of the clearer and more specific Clean Air Amendments of 1970, and with the wording of Section 312(a) of that legislation, as may be seen from the preface to this report.

Within this framework, the estimated direct costs and benefits of air pollution control for industrial and other sources are detailed. Investments are projected through FY 1979 and are shown with the anticipated annual costs in that year. A large number of simplifying assumptions were necessary. Industry and motor-vehicle growth and technology trends were forecast and are described in their appropriate places in the text. Legislation which is pending under the Clean Air Act and which reasonably can be expected to become law was included in the calculations. The best available information on control technologies, associated control costs, and related information were employed. This information is being modified and updated continuously by the growing experience with applied emissions control systems. The situation has been complicated further by recent uncertainty in the overall fuels/energy situation.

It should be noted that this document specifically does not dictate EPA policy with regard to the application of presently available or projected emissions-control technology to any industry or activity. Simplifying assumptions were required in order to estimate the effect of EPA regulations on the industries included herein. The control technologies which were assumed in order to provide these estimates are not specifically required by law or by EPA; no interpretation of the contents of this document to the contrary should be made.

A relatively new and uniform cost estimating methodology has been applied, for the first time and to the maximum extent possible, to these industry groups. The expected minimum and maximum estimates of capital investment, annualized charges, and cash requirement have been treated by a stochastic simulation procedure for deriving the probable range of the estimates.

COSTS OF IMPLEMENTING THE ACT

Estimates of the capital investments required for implementing the Act over the period FY 1971-1979, and the annualized cost are summarized in Table I-1. Costs for the 5-year period FY 1975 through FY 1979 are estimated in Table I-2. Each number in Table I-2 is repeated in the appropriate chapter of this report, where the assumptions and background data are presented and discussed.

It is not possible to estimate actual cash outlays over the reporting period with any precision since the compliance schedules for implementation of state plans are not yet determined. The earlier implementation of state plans is commenced, the larger will be the cash outlay over the period because operation and maintenance expenses will be incurred for more years.

The uncertainties of forecasting even five years into the future are well known. The estimates are based mainly on present technology, with no allowance for innovation. In some situations, control technology has been assumed to be available that has not been commercially demonstrated at the present time. These estimated costs are derived from an extrapolation of current practice; rarely in this century would such a five-year extrapolation have held true.

Estimates of the cost per vehicle of attaining Federal automotive emission standards becoming effective in 1975 and 1976 have been updated. A more complete discussion of the factors entering into this cost may be found in Chapter III.

TABLE I-1. INCREMENTAL NATIONAL COSTS FOR AIR POLLUTION ABATEMENT FROM FY 1971 THROUGH FY 1979 (millions of dollars)

	Cumulative Investment			Annualized Costs (FY 1979)(a)		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Mobile Sources						
Sub-Total	23,107.0	23,107.0	23,107.0	7,382.0(b)	7,382.0(b)	7,382.0(b)
Fossil Fuels						
Steam Electric Power	7,460.0	5,990.0	9,310.0	4,630.0	3,450.0	5,530.0
Commercial and Industrial	5,534.0	3,433.0	7,186.0	1,479.0	667.0	2,212.0
Sub Total: Fossil Fuels	12,994.0	9,423.0	16,496.0	6,109.0	4,117.0	7,742.0
Fuel Industries Group						
Coal Cleaning	15.8	14.5	17.2	3.3	3.1	3.6
Natural Gas Processing	90.0	79.0	105.0	27.3	23.9	30.9
Petroleum Industry	850.0	716.0	993.0	240.8	170.4	302.0
Chemical Industries Group						
Carbon Black	-	-	-	-	-	-
Chlor-Alkali	16.7	15.2	18.4	6.4	6.0	6.8
Nitric Acid	35.4	28.6	42.0	14.2	12.8	15.9
Phosphate Fertilizer	19.4	16.8	21.7	9.8	8.9	10.6
Sulfuric Acid	407.2	366.4	457.1	105.6	96.2	114.3
Metals Industries Group						
Ferroalloy	74.3	70.8	77.9	29.4	28.4	30.7
Foundries(Iron)	339.0	241.0	422.0	180.0	149.0	234.0
Foundries(Steel)	77.2	70.9	83.6	25.5	24.1	27.0
Iron and Steel	2,039.0	1,963.0	2,113.0	687.9	667.9	708.2
Primary Aluminum	1,047.0	998.0	1,098.0	424.0	411.0	438.0
Primary Beryllium	-	-	-	-	-	-
Primary Copper	491.0	449.0	539.0	147.0	138.0	156.0
Primary Lead	27.3	16.8	38.6	6.8	4.1	9.5
Primary Mercury	.9	.8	.9	.2	.2	.3
Primary Zinc	32.4	27.3	39.6	8.2	6.9	10.0
Secondary Aluminum	18.5	15.6	23.4	5.7	4.9	6.8
Secondary Brass and Bronze	9.5	7.2	12.8	3.8	2.9	5.0
Secondary Lead	10.8	6.4	15.1	2.5	1.2	3.8
Secondary Zinc	2.1	1.2	2.9	.7	.4	.9
Burning and Incineration Group						
Dry Cleaning	144.0	120.2	170.3	12.1	6.7	17.9
Sewage Sludge Incineration	62.7	54.5	70.7	15.5	13.7	17.4
Solid Waste Disposal	1,638.0	1,520.0	1,880.0	694.0	619.0	766.0
Teepee Incinerators	-	-	-	-	-	-
Uncontrolled Burning						
Agricultural	-	-	-	-	-	-
Coal Refuse	-	-	-	-	-	-
Forest Fires	-	-	-	-	-	-
Structural Fires	-	-	-	-	-	-
Quarrying and Construction Group						
Asbestos Industry	11.3	10.4	12.9	3.9	3.3	4.3
Asphalt Concrete Industry	604.0	401.0	828.0	119.0	89.0	155.0
Cement Industry	444.0	364.0	526.0	129.0	113.0	144.0
Crushed Stone, Gravel, Sand	-	-	-	-	-	-
Lime Manufacturing	60.8	52.1	68.9	13.3	12.0	14.9
Food and Forest Products Group						
Feed Mills	1,377.0	1,228.0	1,537.0	255.0	231.0	281.0
Grain Handling	985.0	827.0	1,111.0	149.0	125.0	170.0
Kraft Paper	234.0	201.0	272.0	78.0	70.0	92.1
Semichemical Paper	26.7	22.7	31.2	12.3	10.5	14.5
Sub Total: Industrial Sources	11,191.0	9,895.4	12,629.2	3,410.2	3,053.3	3,791.4
TOTAL	47,292.0	42,425.4	52.232.2	16,901.2	14,552.3	18,915.4

(a) Estimated on the basis that all the required capital investment has been made as in FY 1979.

(b) The annualized cost for Mobile Sources for the year FY 1979 is that estimated actually to occur in FY 1979. This annualized cost includes estimated operating and maintenance expense for light and heavy-duty vehicles, plus an estimated $1,085 billion for the cost of implementing in transportation control plan.

TABLE I-2. INCREMENTAL NATIONAL COSTS OF AIR POLLUTION ABATEMENT FOR THE COMING FIVE YEARS (FY 1975-1979) (millions of dollars)

	Investment			Annualized Costs (FY 1979)(a)		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Mobile Sources						
Sub-Total	19,810.0	19,810.0	19,810.0	7,382.0(b)	7,382.0(b)	7,382.0(b)
Fossil Fuels						
Steam Electric Power	5,540.0	4,440.0	7,640.0	4,630.0	3,450.0	5,530.0
Commercial and Industrial	1,175.0	682.9	1,532.1	1,479.0	667.0	2,212.0
Sub Total: Fossil Fuels	6,715.0	5,122.9	9,172.1	6,109.0	4,117.0	7,742.0
Fuel Industries Group						
Coal Cleaning	13.1	12.0	14.2	3.3	3.1	3.6
Natural Gas Processing	89.1	79.1	105.0	27.3	23.9	30.9
Petroleum Industry	450.4	378.3	519.2	240.8	170.4	302.0
Chemical Industries Group						
Carbon Black	-	-	-	-	-	-
Chlor-Alkali	9.3	8.6	10.2	6.4	6.0	6.8
Nitric Acid	32.0	25.7	38.0	14.2	12.8	15.9
Phosphate Fertilizer	19.2	16.1	22.0	9.8	8.9	10.6
Sulfuric Acid	361.5	348.7	405.8	105.6	96.2	114.3
Metals Industries Group						
Ferroalloy	21.4	20.3	22.4	29.4	28.4	30.7
Foundries(Iron)	142.6	109.7	175.3	180.0	149.0	234.0
Foundries(Steel)	17.2	15.3	19.1	25.5	24.1	27.0
Iron and Steel	947.9	910.9	987.5	687.9	667.7	708.2
Primary Aluminum	443.5	415.5	473.3	424.0	411.0	438.0
Primary Beryllium	-	-	-	-	-	-
Primary Copper	85.0	74.0	96.5	147.0	138.0	156.0
Primary Lead	27.3	16.8	38.6	6.8	4.1	9.5
Primary Mercury	.9	.8	.9	.2	.2	.3
Primary Zinc	32.4	27.3	39.6	8.2	6.9	10.0
Secondary Aluminum	8.1	6.8	10.4	5.7	4.9	6.8
Secondary Brass and Bronze	.6	.4	.8	3.8	2.9	5.0
Secondary Lead	2.2	1.3	3.3	2.5	1.2	3.8
Secondary Zinc	.3	.2	.5	.7	.4	.9
Burning and Incineration Group						
Dry Cleaning	123.4	102.6	146.7	12.1	6.7	17.9
Sewage Sludge Incineration	42.7	36.8	48.6	15.5	13.7	17.4
Solid Waste Disposal	1,046.8	949.5	1,157.0	694.0	619.0	766.0
Teepee Incinerators	-	-	-	-	-	-
Uncontrolled Burning						
Agricultural	-	-	-	-	-	-
Coal Refuse	-	-	-	-	-	-
Forest Fires	-	-	-	-	-	-
Structural Fires	-	-	-	-	-	-
Quarrying and Construction Group						
Asbestos Industry	5.0	4.2	5.7	3.9	3.3	4.3
Asphalt Concrete Industry	142.3	85.7	200.8	119.0	89.0	155.0
Cement Industry	93.4	70.0	116.9	129.0	113.0	144.0
Crushed Stone, Gravel, Sand	-	-	-	-	-	-
Lime Manufacturing	15.5	13.6	17.3	13.3	12.0	14.9
Food and Forest Products Group						
Feed Mills	1,108.9	987.4	1,243.7	255.0	231.0	281.0
Grain Handling	860.7	722.9	971.6	149.0	125.0	170.0
Kraft Paper	167.9	143.7	196.2	78.0	70.0	92.1
Semichemical Paper	25.8	22.0	30.2	12.3	10.5	14.5
Sub Total: Industrial Sources	6,336.4	5,606.2	7,117.3	3,410.2	3.053.3	3,791.4
TOTAL	32,861.4	30.539.1	36,009.4	16,901.2	14,552.3	18,915.4

(a) Estimated on the basis that all the required capital investment has been made as in FY 1979.

(b) The annualized cost for Mobile Sources for the year FY 1979 is that estimated actually to occur in FY 1979. This annualized cost includes estimated operating and maintenance expense for light and heavy-duty vehicles, plus an estimated $1,085 billion for the cost of implementing in transportation control plan.

The current estimate of incremental national abatement costs has increased considerably over that presented in the 1973 Cost of Clean Air Report ($23.4 billion in 1973 to $47.3 billion in 1974). The largest increases were in mobile source and fossil fuel burning source abatement costs. These accounted for $9.2 billion apiece. The remainder, almost a $6.0 billion increase, is associated with industrial abatement.

The primary sources of these differences can be identified. In part, the differences are due to the significantly different approaches used in the two reports and the availability of considerably new data. For mobile sources, $3.9 billion of the increase is due to revision of the control cost estimate per vehicle, another $4.2 billion is due to the addition of one more year (1979) to the time period covered. A further increase is due to the inclusion of $1 billion for urban transportation control programs which were omitted from the 1973 report.

The increase in fossil fuel burning source abatement costs is due first to increased costs for control of power plants and for commercial and industrial boilers. Power plant cost increases are due to the addition of $1.8 billion for particulate control which had previously been considered as a standard industry practice prior to promulgation of the Clean Air Act. Also added was $1.7 billion for abatement on one year's growth in power plant capacity (1978-1979), and $1.1 billion due to the increase in estimated unit costs for sulfur oxide control.

The increases in industrial source control cost are distributed over many of the industries studied. The majority of the increase occurred in the feed milling industry ($1.4 billion), solid waste disposal ($1.1 billion) and iron and steel ($1.5 billion). Abatement costs for feed milling had been understated in previous years due to the consideration of only one emission source and 1,112 mills. The current report includes up to seven sources for large mills (four for the smallest) with control costs of about $200,000 per mill. Cost for a similar mill in the previous report was only $15,000 per mill. The current report also uses recent survey data which indicates an industry population of 7,600 mills.

The increase in solid waste disposal cost is due to the inclusion of investment cost for land and equipment ($1.4 billion). The previous report assumed no incremental investment cost over the open-burning alternative. This increase was reduced by $.3 billion due to a revised assumption on the cost of abatement for municipal incinerators. The previous report included the entire cost of new incinerators under the premise that incineration was a required control technique to replace open burning. In contrast, this report includes only the cost of particulate emission control from the incinerators under the alternative premise that most new incinerators would have been built even without the Act. Thus only the incremental cost of particulate control is attributable to the Act. The real cost probably is between these two assumptions.

Other industries for which estimated abatement costs increased significantly were grain milling, and petroleum. These estimates increased by 450 million and 350 million, respectively. As in the case of feed mills, a number of emission sources from grain mills were not considered in the previous report. Inclusion of these sources along with associated control devices resulted in higher abatement costs per mill. New cost data for the petroleum industry was developed by the Industrial Gas Cleaning Institute. The increase in total cost for this industry is the result of the higher unit control costs presented by IGCI.

A significant factor in the cost increases is a change in the base year for the price deflator. The previous year's report used 1970 dollars while the current report uses 1973 dollars. The price indices rose about 15% during this period thus accounting for $2.9 billion of the $19.3 billion increase.

BENEFITS FROM IMPLEMENTING THE ACT

Air pollution has clearly observable effects in terms of increased morbidity and mortality, deterioration of aesthetic qualities, damage to artifacts, soiling, and damage to vegetation. Society's desire to reduce or eliminate these adverse effects has led to establishment of laws, programs and policies designed to control air pollution and improve air quality.

The many kinds of costs pollution imposes upon society are grouped as psychic costs, damage costs, and avoidance costs. Damage costs are those that result in out-of-pocket expenses or direct economic losses because of exposure to pollution. Psychic costs are the mental discomfort and anguish persons feel because of pollution. This includes physical effects, such as smarting eyes and shortness of breath, that people experience, but which do not result in direct expenses or economic losses. Avoidance costs are expenses, such as extra painting, air conditioning, and moving, incurred to reduce or avoid pollution effects.

It is not yet possible to measure all the benefits (reduced pollution costs) of improved air quality. Estimates of some of the benefits have been made and are presented in Table VI-1. These estimates, while providing some understanding of benefits of current programs, are inadequate as a basis for a comparison of the costs and benefits of the entire program or any particular part of the program. The major difficulty is that many benefits have not yet been estimated.

II. GOVERNMENTAL PROGRAMS

INTRODUCTION

This chapter reports projected costs of governmental programs at all levels (Federal, state, and local) directed toward implementation of the purposes of the Clean Air Act Amendments of 1970.

FEDERAL PROGRAMS

Fiscal 1973 Environmental Protection Agency funding for air programs and budget requests for fiscal 1974 are given in Table II-1. Since most programs are organized along functional rather than pollutant lines, it is not possible to allocate costs among the various pollutants.

In addition to expenditures for administration of governmental programs, the Federal government also incurs expenditures to abate emissions from Federally owned and/or operated facilities. Estimated hardware expenditures required to abate such emissions from existing facilities in the period beginning with FY 1974 and beyond are presented in Table II-2.

STATE AND LOCAL PROGRAMS

The Act reaffirms the original jurisdiction of state and local governments over matters pertaining to protection of the quality of the air resource. To aid these units of government in effective prosecution of their responsibilities, EPA maintains ten regional offices covering the ten census regions and devotes by far the largest portion of the budget for air programs to control non-Federal agency development and maintenance. Table II-3 summarizes this support; the state totals in this table include grants to local control agencies during fiscal 1972 with estimates for funding in fiscal 1973 and 1974 within the state.

TABLE II-1. FEDERAL FUNDING FOR AIR PROGRAMS OF THE ENVIRONMENTAL PROTECTION AGENCY (THOUSANDS OF CURRENT DOLLARS) FY 1973-1974

	1973	1974
Research and Development Pollution Processes and Effects	29,624	29,849
Pollution Control Technology	37,758	27,248
Subtotal	67,382	57,097
Abatement and Control Mobile Sources	9,325	9,808
Stationary Source Standards and Guidelines	6,246	6,280
Ambient Trend Monitoring	952	977
Technical Assistance	10,925	9,052
Academic Training Grants	3,415	2,100
Control Agency Support	50,802	51,518
Subtotal	81,665	79,735
Total	149,047	136,834

Source: Agriculture Environmental and Consumer Protection Appropriations for 1974. Hearings before a Subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Third Congress First Session 1973. Part 5.

TABLE II-2. PROJECTED HARDWARE COSTS — FEDERAL FACILITIES (MILLIONS OF CURRENT DOLLARS)

Department of Defense	$141.8
Atomic Energy Commission	.2
Department of Agriculture	3.0
Tennessee Valley Authority	38.1
Department of Transportation	.8
All Agencies	$183.9

Source: Office of Federal Activities, EPA.

TABLE II-3. SUMMARY OF EPA GRANTS FOR STATE AND LOCAL CONTROL AGENCY PROGRAM

State or Territory	1972 Actual	1973 Estimated[a]	1974 Estimated[a]
Alabama	527,324	709,427	861,100
Alaska	69,775	152,518	142,090
Arizona	207,049	512,614	563,400
Arkansas	208,527	280,295	407,000
California	3,690,260	3,893,615	3,769,990
Colorado	900,784	576,524	501,200
Connecticut	1,335,796	1,014,406	839,400
Delaware	189	260,054	212,200
District of Columbia....	225,000	173,088	214,600
Florida	885,741	1,363,097	1,186,600
Georgia	630,218	684,100	1,085,400
Hawaii	96,445	157,395	101,200
Idaho	81,687	141,074	271,200
Illinois	2,423,520	2,830,000	2,640,000
Indiana	826,034	1,109,927	1,738,480
Iowa	559,243	498,841	687,600
Kansas	335,761	470,228	562,324
Kentucky	159,028	1,016,034	766,660
Louisiana	175,000	349,959	807,200
Maine	---	245,349	315,000
Maryland	987,000	852,115	850,800
Massachusetts	794,385	1,247,799	1,375,400
Michigan	1,613,520	2,010,073	1,853,600
Minnesota	365,669	700,097	873,600
Mississippi	421,724	477,699	590,430
Missouri	717,574	1,123,344	956,670
Montana.................	231,460	237,022	222,800
Nebraska	231,929	304,422	274,960
Nevada	245,702	248,532	248,200
New Hampshire	185,409	227,609	238,500
New Jersey	2,118,844	2,583,130	1,734,000
New Mexico	706,440	302,543	328,800
New York	3,967,790	4,232,424	3,755,800
North Carolina	1,489,069	1,050,998	1,154,400
North Dakota............	45,000	62,207	89,600

TABLE II-3 (Continued)

State of Territory	1972 Actual	1973 Estimated[a]	1974 Estimated[a]
Ohio	1,798,153	2,450,000	2,644,390
Oklahoma	484,906	481,408	471,600
Oregon	486,828	667,492	532,300
Pennsylvania	2,080,700	3,645,052	3,259,890
Rhode Island	133,899	197,117	269,000
South Carolina..........	111,783	708,247	719,600
South Dakota............	32,025	86,943	137,870
Tennessee	703,614	1,157,469	910,800
Texas	2,603,299	2,789,526	2,398,800
Utah	---	216,945	319,600
Vermont	224,426	173,669	98,800
Virginia	1,062,000	618,516	1,007,400
Washington	1,129,910	1,194,024	1,003,050
West Virginia	317,620	322,693	500,700
Wisconsin	965,448	900,000	1,039,200
Wyoming	68,133	102,667	59,900
American Samoa	---	33,210	13,800
Guam	54,774	54,990	51,470
Puerto Rico	464,417	512,261	489,800
Virgin Islands	100,043	89,212	71,200
	$40,280,874	$48,500,000	$48,219,374
Grant and contract support for State Implementation Plan revision and development		3,014,500	3,000,000
State Assignee		855,000[c]	280,626[b]
Total		$50,659,500	$51,500,000

Source: Agriculture - Environmental and Consumer Protection appropriations for 1974. Hearings before a subcommittee of the Committee on Appropriations, House of Representatives, Ninety-Third Congress, First Session 1973. Part 5

[a] Dollar amounts are estimates of the actual amounts that may be awarded to States during FY 1973. Estimates include funds to support the program that provides Federal employees to the states on a temporary basis.

[b] Funds for temporary Federal employees assigned to States other than by payment through the grant mechanism.

[c] Reduction resulting from the establishment of the grant and contract review funds.

III. MOBILE SOURCE EMISSION CONTROL

INTRODUCTION

Mobile sources are recognized as significant contributors to national air-quality problems. In areas that are subject to excessive incidences of photochemical smog formation, over half the reactants can generally be attributed to motor-vehicle emissions. Similarly, motor-vehicle emissions frequently are the source of excessive concentrations of carbon monoxide in high-traffic-density urban areas during traffic peaks. In many cities, aircraft operations are the source of high levels of carbon monoxide, hydrocarbons, nitrogen oxides, and particulates in the vicinity of air-traffic terminals.

Passenger cars and light trucks have been highly significant and visible pollutant sources, and accordingly, have been intensively controlled by the Federal Government beginning as early as 1968. Federal controls on heavy-duty motor vehicles have been in effect since 1970, and Federal aircraft emission controls will be implemented beginning in 1974.

Other mobile sources such as motorcycles; railroad locomotives; off-road farm, construction, and garden equipment; and marine engines have been under study by EPA, but no regulations for these sources have been promulgated to date.

This chapter describes briefly the applicable standards and technology employed for mobile-source emission controls, and presents estimates for the equipment cost and operating cost of these controls. Totals are given for the 1968-1979 time interval.

LIGHT-DUTY VEHICLE CONTROLS

Standards

Since 1968, the Federal Government has regulated the output of air pollutants from the exhaust of new light-duty motor vehicles. Emission standards are expressed in terms of maximum levels of gaseous emissions per mile permitted from the vehicle while operating on a prescribed duty cycle. Sampling procedures and test equipment are also prescribed by the regulations. While the standards apply only to new vehicles, the certification procedure requires that test cars meet emission standards after being driven over a prescribed durability schedule.

Both emission levels and test procedures have been revised periodically in several steps of increasing stringency. Changes in the

Federal Test Procedure were implemented for the 1972 and 1975 model years. Changes in emission levels were prescribed by the Environmental Protection Agency (or its predecessors) for 1970, and 1973 (NO_x), and were based largely on evolving technology for emission control. In effect, the 1973/74 Federal Standards required a reduction in hydrocarbon (HC) and carbon monoxide (CO) exhaust emissions of about 66 percent and a reduction in oxides of nitrogen (NO_x) of 44 percent from uncontrolled (pre-1968) levels.

The 1970 Amendments to the Clean Air Act called for the Administrator to prescribe 1975 Federal emission standards effecting a 90 percent reduction in the HC and CO emissions from 1970 levels, and to prescribe 1976 Federal standards effecting a 90 percent reduction in NO_x emissions from 1971 levels. The 1970 Amendments further gave the Administrator the authority to grant a 1-year suspension of the 1975 and 1976 standards under specified conditions if it could be established that effective control technology was not available for compliance.

On April 11, 1973, the Administrator announced his decision (III-1)* to suspend the 1975 statutory Federal Motor Vehicle Emissions Standards covering carbon monoxide and hydrocarbon for a period of 1 year. After extensive hearings in March, 1973, the Administrator found that, although the necessary technology existed to meet the 1975 standards (based on the use of catalytic converters) there was a high degree of uncertainty concerning the industry's ability to certify and produce catalyst-equipped cars in 1975 in large enough numbers to meet production requirements for their full model line. In addition, in-use reliability of the catalysts had not been established. Because of this, it was found that the risk of introducing catalysts on all vehicles in 1975 outweighed the risk to human health if the standards were delayed.

The suspension was applied in two parts:

- National 1975 interim standards were established which are more strict than standards now in force, but which should not necessarily require catalysts on the majority of vehicles sold.
- More stringent standards were established for vehicles sold only in California which would require catalysts on cars sold in that state. The California waiver provision in the Clean Air Act was utilized to establish the California HC and NO_x standards, while a more stringent standard was prescribed for CO.

The 1975 statutory standards as originally established were to be applicable to all cars sold in the U.S. in 1976.

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* Numbers in parentheses denote references listed at the end of this chapter.

Similarly, the Administrator's decision (III-2) to suspend the 1976 Clean Air Act Standards was announced on July 31, 1973. This decision was based on the belief that technological success in meeting the 1976 statutory standards could not be predicted reasonably. In applying this suspension, the Administrator established an interim NO_x Federal standard of 2.0 gram per mile which is attainable with existing advanced emission-control technology.

Table III-1 summarizes the resulting present and future Federal exhaust-emission standards for light-duty passenger cars.

Federal regulations also prescribe control of crankcase blowby and evaporative fuel emissions from light-duty vehicles. Crankcase emissions have been virtually eliminated since 1963 by the use of positive crankcase ventilation (PCV) valves. Federal regulations have also prescribed evaporative fuel-emission controls beginning with the 1971 model year which impose a limit of 2.0 grams of hydrocarbons per test.

Beginning in 1975, light-duty trucks (less than 6,000 lb GVW) will be regulated as a separate vehicle class, while previously they will have been subject to the same standards as passenger cars.

Emission standards applicable to light-duty trucks are shown as Table III-2. As shown, the 1975 standards are somewhat less stringent than 1975 National Interim standards for passenger cars.

Emission-Control Equipment Costs

Control Devices, 1968-74 Model Years

In the years 1968 through 1972, compliance with Federal emission standards was achieved principally by two types of engine modification:

- Changes in the engine fuel-induction system, ignition system, and combustion-chamber design
- The above changes and the addition of air injection into the exhaust manifold(s).

Changes to the fuel-induction system included recalibration and tighter precision of carburetor fuel metering, a system to preheat and control the temperature of intake air, modification of carburetor idle-setting controls, and choke-calibration changes. Various types of ignition-system modifications were used to retard ignition timing at idle and low speed. Some changes in combustion-chamber shape were made which included lowering the compression ratio in 1971 for operation on nonleaded gasoline. Valve seats were hardened on some engine models to reduce mechanical problems associated with the use of nonleaded gasoline.

TABLE III-1. FEDERAL EXHAUST EMISSION STANDARDS AND CONTROL LEVELS FOR LIGHT-DUTY VEHICLES [(a)]

(Under 6,000 lb Gross Vehicle Weight)

Model Year of Implementation	Standard	Hydrocarbons		Carbon Monoxide		Nitrogen Oxides	
		Gram/Mile	Reduction, percent	Gram/Mile	Reduction, percent	Gram/Mile	Reduction, percent
Pre-1968	Uncontrolled vehicles	8.7	--	87	--	5.5	--
1973/74	1973/74 Federal Standards	3.0	66	28	67	3.1	44
1975	1975 National Interim Standards[(b)]	1.5	83	15	83	3.1	44
1976	1975 Statutory Clean Air Standards and 1976 Interim Standards	0.41	95	3.4	96	2.0	64
1977	1976 Statutory Clean Air Standards	0.41	95	3.4	96	0.4	93

(a) Emission levels are measured on the 1975 Constant Volume Sample, Cold/Hot Weighing Mass Test Procedures (CVS-CH).

(b) Interim California Standards: 0.9 gram/mile hydrocarbons, 9.0 gram/mile carbon monoxide, and 2.0 gram/mile nitrogen oxides.

TABLE III-2. FEDERAL STANDARDS FOR LIGHT-DUTY TRUCK EMISSIONS[a]

Pollutant	Emission Standard	
	1968-74	1975-76[b]
HC	Subject to light-duty vehicle emission standards	2.0 gram/mile
CO	Ditto	20 gram/mile
NO_x	"	3.1 gram/mile

(a) Motor vehicles rated at 6,000 lb GVW or less designed primarily for transportation of property, or derivatives of such vehicles.

(b) Emissions averaged over a CVC-CH driving-cycle test.

In addition, some engine models incorporated an air pump and an air-distribution system for the injection of air into the exhaust manifold(s).

Beginning in 1973 (1972 in California) changes in valve timing and/or the use of exhaust gas recirculation (EGR) were incorporated for NO_x control.

Evaporative fuel emission controls used since 1971 employ charcoal canisters or a system to store evaporative losses in the engine crankcase.

A breakdown of EPA (III-3) and National Academy of Science (NAS) (III-4) initial-equipment cost estimates for 1968-74 emission controls is shown as Table III-3. The investment costs shown are cumulative and result in an estimated average list price increase of $82.50 for the 1973/74 models. This estimate is based on an emission-control system not employing air injection.

Control Devices, 1975 and 1976 Model Years

The statutory Clean Air Act exhaust emissions standards as initially established for 1975 model-year automobiles are significantly more stringent than previous standards. To this effect, the U.S. automobile industry has concluded that engine modifications will not be sufficient in themselves to meet the Federal standards and that postcombustion emission control devices will be required. The particular devices selected will primarily be concerned with the reduction of HC and CO emissions.

For light-duty motor vehicles, the NAS Committee on Motor Vehicle Emissions (III-4) concluded that four types of systems could meet the 1975 Federal Statutory Clean Air emission standards. These are the following:

- A modified conventional engine equipped with an oxidation catalyst
- A carbureted stratified-charge engine
- A rotary (Wankel) engine equipped with an exhaust thermal reactor
- A diesel engine.

The Committee also recognized that 1975 vehicles using Wankel engines or catalyst-equipped, spark-ignition piston engines might use significantly more fuel than the 1973 model-year automobile. Carbureted stratified-charge engines are expected to suffer only a slight fuel penalty, and the diesel engine will actually offer improved fuel economy--enough to offset its higher initial cost within a few years of driving. However, recent data from the automobile industry indicate that those

TABLE III-3. ESTIMATED AUTOMOTIVE EMISSION-CONTROL EQUIPMENT COST, 1968-74

Year	Item	List Price[a] EPA[b]	List Price[a] NAS[c]
1968-69	Positive crankcase ventilation (PCV) valve	$ 0.40	$ 2.85
	Inlet air temperature control	5.00	3.80
1970-72	Fuel evaporation control system	13.00	14.30
	Idle control solenoid	11.10	4.75
	Carburetor changes	3.00	0.95
	Hardened valves and seats (for unleaded gasoline)	2.00	1.90
	Transmission control system	--	3.80
	Ignition timing	--	0.95
	Choke heat bypass	--	4.18
	Compression ratio changes	--	1.90
	Cumulative costs through 1972	$34.50	$39.38
1973-74[d,e]	Exhaust gas recirculation (EGR), 11-14 percent	24.00	9.50
	Speed controlled spark timing	24.00	0.95
	Precision cams, bores, pistons	--	3.80
	Transmission changes	--	0.95
	Cumulative costs through 1974	$82.50	$54.53

(a) List price includes both dealer and manufacturers profits.

(b) From Reference III-3.

(c) From Reference III-4.

(d) Federal emission standards for 1973 and 1974 are identical. Manufacturers may add additional EGR to some of their 1974 vehicles to meet more restrictive 1974 California standards for NO_x.

(e) This emission control configuration will most likely be installed on noncatalytic 1975 model-year autos.

1975 conventionally powered vehicles equipped with catalytic converters and meeting the statutory standards may have little or no fuel penalty compared with 1973 vehicles.

While each have shown the ability to reduce emissions, the catalytic converters were clearly preferred by the U.S. automobile inindustry for automobiles meeting the 1975 statutory standard.

With the 1-year suspension of 1975 statutory standards having been granted by the Administrator and with the establishment of 1975 Interim Federal Standards (not necessarily requiring catalysts) and 1975 Interim California Standards (requiring catalysts), it is now apparent that two types of emission-control systems will be used for the 1975 model year: (1) catalyst-equipped systems, and (2) systems incorporating advanced engine modifications but not incorporating catalysts.

For the 1976 model year, it can be expected that the emission-control equipment will be the same as that for the 1975 model-year catalytic systems with the addition of proportional EGR, if not previously used, or with recalibrated EGR devices, if previously used, to meet the Federal 1976 model year interim NO_x standard of 2.0 g/mi established in conjunction with the 1-year suspension of the 1976 statutory clear air standards.

Shown as Table III-4 are estimated costs of emission-control equipment for the 1975 and 1976 model years. The estimated cost increment for 1975 noncatalytic systems over 1973-74 models is $95.00, and the addition of an oxidation catalyst is estimated to cost $90.00. Thus, cumulative equipment costs per vehicle are estimated to be $177.50 for noncatalytic systems and $267.50 for the catalyst-equipped systems.

The average 1975 model-year equipment costs will, of course, depend upon the fraction of vehicles sold with catalytic systems. It is presently estimated from industry sources that about 75 percent of the 1975 model-year vehicles will be catalyst equipped: all California cars (over 10 percent of national sales) and a substantial segment of the remaining vehicles. If this prediction proves to be accurate, the average national cost can be estimated as follows:

	Cumulative 1975 Model Year Equipment Cost		Estimated Fraction of 1975 Sales		
Catalytic Systems	$267.50	x	0.75	=	$200.62
Noncatalytic Systems	177.50	x	0.25	=	44.38
Estimated Average Cumulative Cost for 1975 Model Year Equipment					$245.00

TABLE III-4. ESTIMATED AUTOMOTIVE EMISSION-CONTROL EQUIPMENT COST, 1975 AND 1976 MODEL YEARS

Year	Item	List Price(a) EPA(b)	List Price(a) NAS(c)	List Price(a) Industry(d)
	Cumulative costs through 1974(e)	$ 82.50	$ 54.53	$ 83
1975	Quick heat manifold	5.00	4.75	--
	High energy ignition	15.00	12.35	--
	Advanced carburetor	15.00	14.25	--
	Proportional EGR	20.00	30.00(f)	--
	Air injection	40.00	43.32(g)	--
	Subtotal for noncatalytic systems	95.00	104.67	75-120
Some 1975 and all 1976	Oxidation catalyst(h) (includes long-life exhaust system)	90.00	54.70	75-110
	Cooling system changes	--	1.90	--
	Body revisions and material changes	--	2.85	--
	Assembly line changes and testing	--	5.65	--
	Subtotal	90.00	65.10	75-110
	Cumulative costs through 1975	$267.50	$224.30	$233-313

(a) List price includes both dealer and manufacturer profits.

(b) From Reference III-3.

(c) National Academy of Science, Reference III-4.

(d) Estimated industry ranges, from data submitted by the domestic manufacturers.

(e) See Table III-3.

(f) 1974 through 1975 model years.

(g) 1973 through 1975 model years.

(h) This emission-control configuration will most likely be deferred to 1976 model-year vehicles as a result of the 1975-standards-suspension decision.

Control Devices, 1977 Model Year

With the implementation of the 1977 model year (1976 Statutory Clean Air) Federal emission standards, an 80 percent reduction in NO_x standards from the previous year (90 percent from 1971) will have been effected. Additional control technology will be required to achieve this substantial NO_x-level reduction.

The capability of many different systems to achieve the statutory 1976 emission standards has been investigated. Some of these systems involve the use of alternative (noninternal-combustion Otto cycle) engines (e.g., Rankine cycle, Brayton cycle, Diesel, Stirling). Such systems are not considered candidates because insufficient lead time remains to mass produce a significant number of passenger cars powered by alternative engines in model year 1977 and no vehicle powered by an alternative engine has yet demonstrated the capability to meet all of the requirements of the Clean Air Act.

Eight systems that are applicable to modified conventional internal combustion engines have demonstrated the capability to meet the levels required for 1976 at low mileage. These systems are:

- Dual catalyst
- Three-way catalyst
- Dual thermal reactor and reduction catalyst
- Stratified charge engine
- Fast-burn combustion system
- Thermal reactor plus exhaust-gas recirculation (EGR)
- Oxidation catalyst plus EGR
- Triple-bed catalyst.

At this time the dual catalyst system has received the most attention and is considered the most advanced of the above options.

The dual catalyst system is compatible with the oxidation catalyst system which many manufacturers will use to meet the 1975 California interim standards. The reduction catalyst used in this system is similar to an oxidation catalyst. No drastic modifications are made to the 1975-type system other than the installation of the reduction catalyst upstream of the oxidation catalyst. Minor changes include recalibration of the carburetion and different plumbing of the air injection system. Accordingly, the estimated cost of emission-control equipment for the 1977 model year (meeting 1976 statutory clean air standards) are based on the use of a dual catalyst. Various estimates of this cost are shown as Table III-5. The EPA estimate of incremental cost is $60 for the addition of a reducing catalyst. The estimated cumulative cost through 1977 is $327.50.

Incremental Maintenance Costs

The additional per-vehicle maintenance costs attributable to emission-control devices has been estimated by EPA (III-5) to be $16 for

TABLE III-5. ESTIMATED AUTOMOTIVE EMISSION-CONTROL EQUIPMENT COST, 1977 MODEL YEAR

Year	Item	List Price(a)		
		EPA(b)	NAS(c)	Industry(d)
	Cumulative costs through 1976	$267.50	$224.30	$273-313
1977	Reduction catalyst	60(e)	74.10	50-90
	Electronic control	--	47.50	15-25
	Sensors	--	5.70	--
	Subtotal	60	127.30	65-115
	Cumulative costs through 1977	$327.50	$351.60	$388-428

(a) List price includes both dealer and manufacturer profits.

(b) From Reference III-3.

(c) National Academy of Science, Reference III-4.

(d) Estimated industry ranges.

(e) Revised EPA estimate, April, 1973.

model years 1968 through 1974. For post-1974 systems, there will be additional maintenance costs associated with catalyst replacement as well as certain benefits associated with high-energy electronic ignition systems and long-life exhaust systems. It is estimated that these benefits will result in a saving of approximately $3 from 1973 maintenance costs. Although future catalyst-replacement requirements are uncertain at this time, the additional maintenance cost for catalytic converters is based on the assumption that one catalyst change will be required over the life of the vehicle. Averaged over 10 years, this cost is estimated to be $7. Hence, it is estimated that the average yearly cumulative additional maintenance costs for 1975 model-year emission control equipment will be $13 for noncatalytic systems and $20 with an oxidizing catalyst.

For the 1977-79 model year vehicles, assuming dual-catalyst systems are employed, an additional $8 average annual maintenance cost increment is predicted, primarily associated with the replacement of the additional catalytic converter.

Annual maintenance cost penalties for the various model years are shown as Table III-6. The value for 1975 is based on an assumption that 75 percent of vehicles sold in the U.S. will be catalyst equipped.

Fuel-Consumption Penalties

The average fuel economy of motor vehicles has been decreasing gradually over the past several years. This change can be attributed to variations in vehicle weight, engine size, optional equipment, and to the effects of emission-control equipment. In particular, the specific control measures that adversely effect fuel consumption are retarded ignition timing, reduced compression ratio, and exhaust-gas recirculation.

In 1973, the EPA published the results of an extensive study (III-6) of passenger-car fuel economy involving tests of nearly 4,000 vehicles ranging from 1957 production models to 1975 prototypes. From this study, it was concluded that, for current vehicles, weight is the dominant factor affecting fuel economy. The use of emission controls has had little effect on lighter vehicles (under 3,700 lb inertia weight), but heavier 1973 model-year cars have suffered fuel consumption penalties ranging from 14 to 18 percent. On a sales-weighted average, it is estimated that the loss in fuel economy due to emission controls for the 1973 models is 10.1 percent compared to that for 1957-1967 uncontrolled vehicles.

Penalties for the years 1968-1972 have been less severe but significant. EPA estimates for fuel consumption penalties by model year are shown as Table III-7. The 1974 model year fuel economy penalty estimate has been derived from 1974 certification data (III-7) and 1972 sales data. A shift in sales toward lighter cars will offset this.

TABLE III-6. ESTIMATED INCREMENTAL MAINTENANCE COSTS FOR VEHICLE EMISSION-CONTROL SYSTEMS

Model Year	Annual Maintenance Cost Increase Per Vehicle
1968-72	$16.00
1973-74	16.00
1975(a)	18.00
1976	20.00
1977-79(b)	28.00

Source: Environmental Protection Agency, Reference III-5.

(a) Based on assumption that 75 percent of 1975 vehicles sold will employ catalytic emission-control systems.

(b) Based on the use of a dual-catalyst system.

TABLE III-7. EFFECT OF EMISSION CONTROL ON LIGHT-DUTY VEHICLE FUEL ECONOMY

Model Year	Fuel Economy Loss, percent
1957-67 (Uncontrolled)	Baseline
1968	4.3
1969	5.3
1970	4.7
1971	7.6
1972	7.3
1973	10.1
1974	9
1975(a)	3
1976	6
1977-79(b)	7

Source: Environmental Protection Agency.

(a) No firm basis is presently available for estimating effects of emission control on fuel economy for the period 1975-1979.

(b) Based on the use of a dual-catalyst system with an advanced fuel-metering system or 3-way catalyst with feedback control.

For subsequent years, of course, fuel economy estimates are less certain. Although early 1975 prototype systems meeting the statutory HC and CO standards had, in general, shown additional fuel-consumption penalties, various industry sources have recently indicated that catalytic systems meeting 1975 clean air statutory standards may deliver fuel economy superior to 1973 vehicles. Accordingly, the fuel-consumption penalty for 1976 model year listed in III-7 is assumed to be about a 3% loss over 1975 vehicles meeting the interim standards for HC and Co, and an additional 1% penalty is assumed for the 1977 model year to result from the more stringent NO_x regulation for that year.

For 1977 model-year dual-catalyst systems, no firm estimate of fuel consumption is possible at this time. However, with the use of a reducing catalyst, it may be possible to eliminate some of the engine modifications previously used for NO_x control, and, further, it is foreseen that the use of excessively rich fuel/air mixtures is not inherent in the control of NO_x by a catalyst. Most of the excess fuel used in prototype systems is not needed for the operation of the catalyst itself, but to protect against exposing the reducing catalyst to oxidizing (lean) conditions due to the occurrence of unwanted fluctuations in the fuel/air ratio. To the extent that the accuracy of fuel-metering systems can be improved to eliminate these fluctuations, this margin for error can be reduced and fuel economy can accordingly be improved. In fact, it appears it may be possible to restore fuel consumption to pre-1968 levels with catalysts for NO_x control. However, the fuel consumption penalty for the 1977 model year is shown in Table III-7 as a slight loss over the previous year since there is no firm basis at this time for predicting how much lower it may be.

Light-Duty-Truck Control Costs

The per-vehicle costs for emission control for light-duty trucks can be considered equivalent to that for passenger cars through 1974, since both types of vehicles are covered by the same standards and the powerplants used are basically the same.

With light-duty trucks covered by separate and less stringent standards beginning in 1975, per-vehicle control costs for light trucks will become somewhat less than for passenger cars.

For this report, it is assumed that costs associated with emission controls for light-duty trucks of model years 1975-79 will be the same as costs associated with noncatalytic 1975 passenger-car emission control systems.

Fuel Cost Increases

On January 10, 1973, EPA promulgated regulations requiring that by July 1, 1974, gasoline marketers make 91 research octane number (RON) lead-free gasoline generally available for use in vehicles equipped with lead-sensitive control systems. At the same time EPA reproposed low-lead regulations, requiring that the lead content of leaded gasolines be reduced to an average of 1.25 grams per gallon (gpg) by January 1, 1978, for the purpose of protecting the public health. On November 28, 1973, EPA announced (III-8) that revised lead regulations had been promulgated which provide for a phased reduction in the average lead content of all grades of gasoline produced by any refinery over a 4-year period. Refineries are restricted to 1.7 gpg beginning January 1, 1975, with annual reductions to 0.5 gpg by January 1, 1979. The new regulations do not offset the earlier regulation requiring the general availability of at least one grade of lead-free gasoline by July 1, 1974.

The promulgated schedule stretches the removal over a relatively long period of time and the allowable lead content of leaded gasoline in the national pool is not significantly lowered until 1977-1978. Two of the most important reasons for the lengthiness of the promulgated schedule are to ensure an adequate margin of industry construction capability and to minimize refinery raw material penalties.

For the next several years, the lead content of leaded gasoline will remain relatively high. Our latest national projections on the allowable lead content of leaded gasolines are summarized in the following table, which shows the lead phase-down schedule as promulgated and our best estimates of the lead-free need. From these we have calculated the allowable lead in leaded gasoline. Note that the allowable lead increases after 1979 because the phase-down remains constant while the number of cars using leaded gasoline decreases each year. Total lead emissions from all gasoline, however, will remain relatively constant.

TABLE III-8. ANTICIPATED EFFECT OF LEAD PHASE-DOWN SCHEDULE

Year	Promulgated Lead Phase-down grams/gallon	Portion of Pool Lead-free (%)	Allowable Lead in Leaded Gasoline grams/gallon
1974	---	7	2.0 to 2.2*
1975	1.7	15	2.0
1976	1.4	30	2.0
1977	1.0	44	1.78
1978	0.8	51	1.63
1979	0.5	63	1.27
1980	0.5	72	1.66

*Current average.

EPA's analysis (III-9) shows that the lead-free regulations will cost the consumer approximately $2.4 billion from 1974 to 1979. Ninety percent of this cost is attributable to the need to install a third pump at service stations and to modify the gasoline trailers and storage tankers to distribute lead-free gasoline. The impact of the low-lead regulation over the same period has been estimated at $200 million. Taken together, the total impact on the consumer will be around $2.6 billion. This translates into less than a 0.4 cent per gallon increase in the cost of gasoline given that nearly 700 billion gallons of gasoline will be consumed during the period.

The analysis also considers the energy impact of the lead regulations in combination with fuel economy improvements afforded by the use of catalysts. It is true that if one considers the impact of the lead regulations on petroleum refineries separately, a finite penalty results that affects our current energy shortage. However, when the most recent information concerning fuel economy is included, we find that a net energy savings emerges. These data on energy impact are summarized in the following tabulation.

Energy Impact of EPA's Lead Regulations and Emission Standards
(thousands of barrels per day)

	1975	1977	1980
Penalty			
Lead-free	30	35	65
Low-lead	20	70	20
	50	105	85
Fuel Economy Savings			
1975/76 Emission Standards	(55)	148	180
Net Crude (Penalty)/Savings	(5)	43	95

The energy penalty is the BTU content of the original crude oil which is consumed in refining in order to raise the octane level of gasoline. Most of the energy will be lost as heat in hydrocracking, reforming and alkylation. In 1975, part of the loss will be due to dislocations in existing product logistics. By 1977, the penalties for lead-free and low-lead gasoline will be rising in proportion to the amount of those products required by new cars. The penalty for low lead gasoline will gradually decrease after 1977.

Aggregate National Costs for Light-Duty-Vehicle Emission Controls

Costs to the nation for light-duty-vehicle emission control will be comprised of the aggregate of equipment, maintenance, and fuel-consumption cost increments attributable to the control devices. Since the various costs attributable to emission controls are different for each model year, total costs to the nation have been estimated separately for each model year using vehicle-population data for previous years and projections for future years.

Vehicle Population Estimates

Registration data (III-10) are available at this time for vehicle model years up to 1972 for each calendar year up to 1972. Estimates of vehicle populations for future years are based in part on the U. S. passenger-vehicle sales projections shown as Table III-9. These projections were made prior to the major downturn in new car sales late in 1973 and so do not reflect the market shifts which may occur. Using these projections and typical scrappage-rate histories for previous model years, the vehicle population trends shown in Figure III-1 are estimated. As shown, uncontrolled passenger vehicles will constitute only 6 percent of the population by 1979, and 29 percent of the vehicles will have been manufactured under 1970 Clean Air Act stabilization level controls.

In estimating light-duty truck population, it is assumed that survival factors for presently registered light trucks will be the same as those for passenger cars, and, further, that new registrations of light trucks will be 1.5 million annually for the interval 1975-79. This is a revision of the projections for truck sales presented in Reference III-11 which factors in the recent rapid increase in sale of vehicles in this category.

Estimated Total Costs, 1968-1979

A breakdown of annual National cost estimates for light-duty-vehicle emission control is presented in Table III-10. Equipment costs for each calendar year are taken as the equipment cost attributable to the new model-year vehicles. Maintenance and equipment costs for each calendar year are attributable to all controlled vehicles over 1 year old in the vehicle population for that year. Costs attributable to fuel price penalties are applied to all gasoline consumed by light-duty vehicles for the affected years.

TABLE III-9 PROJECTED UNITED STATES SALES OF LIGHT-DUTY PASSENGER VEHICLES

Model Year	Sales, millions of vehicles
1973	11.83
1974	10.7
1975	10.9
1976	11.2
1977	11.5
1978	11.7
1979	12.0

Source: Department of Transportation, Reference III-10.

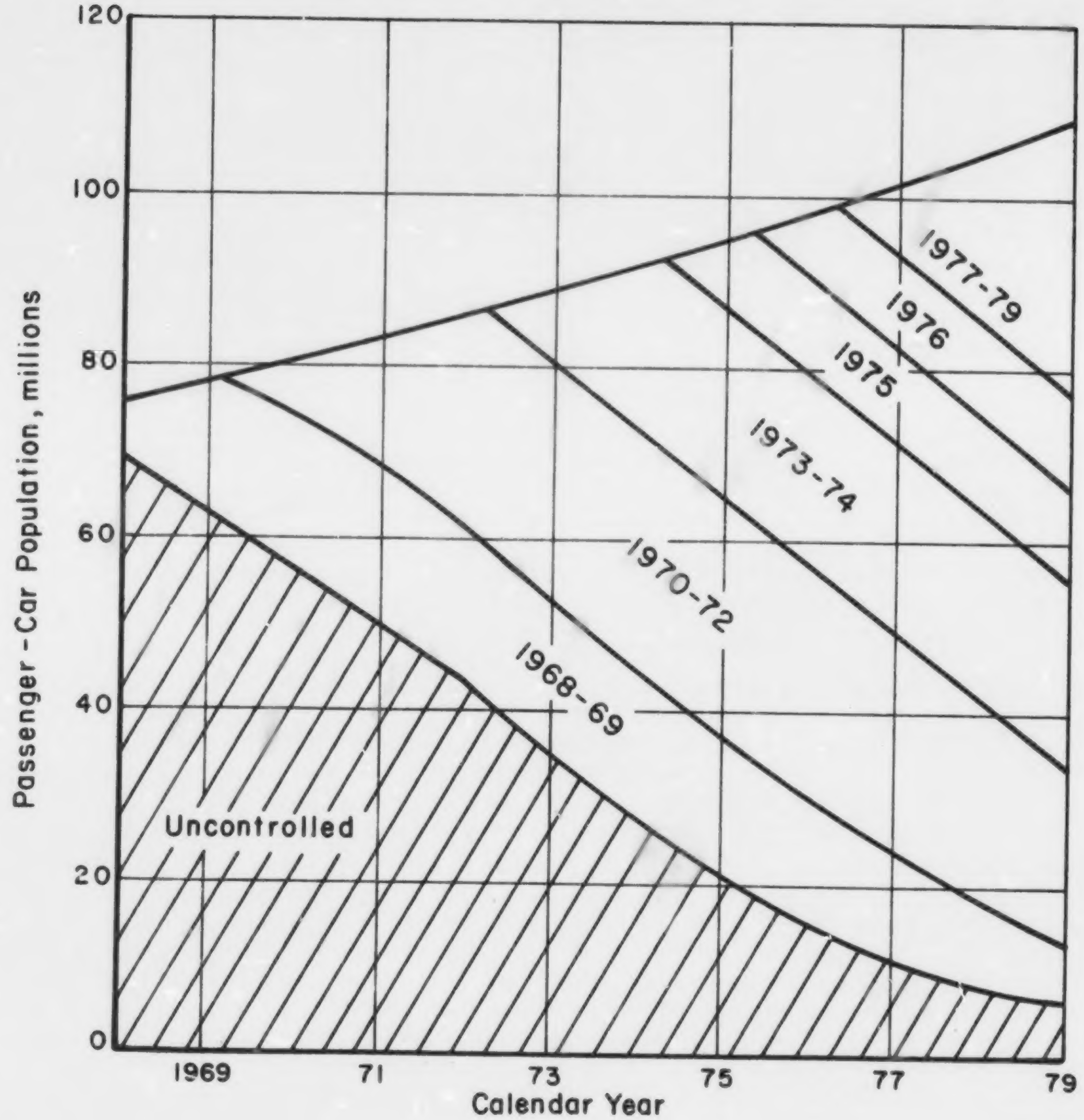

FIGURE III-1. ESTIMATED PASSENGER-CAR POPULATION

As shown in Table III-10, estimated cumulative costs are $8.9 billion as of 1973. Total annual costs to the nation will continue to increase as the result of both increasingly stringent control and an increasing population of controlled vehicles. Annual costs for 1974 and 1979 are estimated to be 4.62 and 10.15 billion dollars, respectively. Cumulative national costs are presently estimated to reach about $13.5 billion by 1974 and $57.3 billion by 1979.

State Transportation Controls

The Clean Air Act Amendments of 1970 directed EPA to set National air quality standards which would protect the public health and welfare from the known effects of the major air pollutants. In 1971, such air quality standards were established for six pollutants, including the four primarily associated with motor vehicles, i.e., carbon monoxide (CO), nitrogen dioxide (NO_2), photochemical oxidant (OX), and hydrocarbons (HC). Hydrocarbons are reactants in the formation of oxidants and at ambient concentrations have no known health effects.

The standards for the motor-vehicle-related pollutants have been exceeded in a number of our major urban areas. Out of the 247 Air Quality Control Regions (AQCR's) in the United States, in the period 1970-71, 54 regions exceeded the air quality standard for oxidant, 29 exceeded the carbon monoxide standard, and 2 exceeded the nitrogen dioxide standard. In all, 58 AQCR's representing nearly 55 percent of the nation's population exceeded the ambient-air-quality standards for one or more or these pollutants.

The Environmental Protection Agency's plan (III-12) to achieve the air quality standards on a National basis includes the implementation of controls on stationary sources (power plants, industrial facilities, and general area sources), the Federal new-car emission standards, and in-use vehicle emission controls. The anticipated reductions in pollutant concentrations resulting from the implementation of stationary-source controls and new-vehicle emission standards are projected to reduce the number of AQCR's exceeding the air quality standards to 29 by 1975. These include approximately 40 percent of the nation's population.

Having controlled the emissions from stationary sources and new vehicles to the extent possible, those states containing the AQCR's still projected to exceed the air quality standards will be required to implement appropriate transportation controls (i.e., controls of in-use vehicles) to meet the requirements of the Clean Air Act. The control of emissions from these vehicles is essential because, although motor vehicles are not the only source of HC, CO, and NO_x emissions, they are the primary source of these pollutants in our urban areas. Table III-11 shows the general range of relative contributions of emission sources in our urban areas. The data clearly indicate the importance of automotive emission controls.

TABLE III-10. ESTIMATED NATIONAL COSTS ATTRIBUTABLE TO LIGHT-DUTY VEHICLE EMISSION CONTROLS[a]

Cost-Increment Category	Annual National Cost, $ billions											
	1968[b]	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Equipment	0.05	0.06	0.19	0.35	0.40	1.13	1.01	2.94	3.26	4.03	4.10	4.20
Maintenance	0	0.11	0.28	0.44	0.58	0.76	0.96	1.20	1.31	1.47	1.69	1.92
Fuel-consumption penalties[c]	0.11	0.36	0.50	0.65	1.12	1.76	2.30	2.69	2.89	3.04	3.29	3.54
Fuel price penalties	0	0	0	0	0	0	0.35	0.41	0.43	0.45	0.47	0.49
Annual total	0.16	0.53	0.97	1.44	2.10	3.65	4.62	7.24	7.89	8.99	9.55	10.15
Cumulative national total	0.16	0.69	1.66	3.10	5.20	8.85	13.47	20.71	28.60	37.59	47.14	57.29

(a) Vehicles less than 6,000 lb GVW including light-duty trucks.

(b) No costs incurred nationally prior to 1968.

(c) Fuel prices assumed: $0.36/gal, 1968/71; $0.40/gal 1972; $0.45/gal, 1973; $0.50/gal, 1974-79.

At present, there are transportation control plans for 38 cities located in 24 states covering approximately 43% of the United States population. Additional areas that will probably require control plans in the near future include some 19 cities in 13 states. If this occurs, 57 cities representing over half of the nation's population will be subject to some type of transportation controls (including additional stationary source controls). Only 29 AQCR's have transportation control measures; the additional AQCR's achieve ambient standards through stationary source control alone.

Plans for 11 of the 38 cities were totally approvable as submitted by the states. In the other 27 cities, plans were either partially approved by EPA and required additional EPA-devised strategies, or states failed to submit any plans, necessitating EPA development of complete transportation plans.

In 21 of the cities, the plans had to address both a carbon monoxide and oxidant problem. Strategies designed to achieve satisfactory oxidant levels are sufficient to also ensure the attainment of the CO standards. In 10 of the cities there is only an oxidant problem, while 7 must control only carbon monoxide.

The number of transportation control plans containing various measures are as follows:

o Inspection/Maintenance	27
o Mass Transit Improvements	25
o Retrofits	21
o Parking Supply Restrictions	20
o Additional Stationary Source Controls	18
o Gas Limitation for Mid-1977	10

In addition to emissions reductions, there are substantial energy savings possible from the implementation of the plans. The vehicle miles traveled reduction strategies, when fully operational, could result in fuel savings of over 5 million gallons each day without the implementation of gasoline rationing measures.

TABLE III-11. MIX OF EMISSION SOURCES IN URBAN AREAS--1971

	Percent of Total Emissions		
Pollutant	Automobiles	Trucks, Buses, and Motorcycles	Stationary Sources
CO	77-87	8-10	3-15
HC	50-65	5-10	25-45
NO_x	40-50	8-13	37-52

Source: Environmental Protection Agency, Reference III-11.

The control of in-use vehicle emissions generally takes one or more of the following forms:

- The use of equipment to control emission of gasoline vapor from service stations during vehicle refueling (not strictly a vehicle-emission control, but very closely related).
- The reduction of vehicle miles traveled (VMT) through the use of various measures including traffic controls, mass transit augmentation, parking restrictions, car-pool systems, and gasoline supply limitations.
- The mandatory inspection and maintenance (I/M) of vehicles to ascertain and maintain adequate emissions performance.
- The retrofitting of vehicles with systems or devices which directly reduce exhaust emissions.

Vehicle control measures being considered in AQCR implementation plans and their effects, applicability, and estimated cost per vehicle are listed in Table III-12.

Vehicle Miles Traveled (VMT) controls are not listed in Table III-12 because the costs and impacts are not readily identifiable. Assuming that VMT reductions are compensated for by increased use of car pools or mass transit, a reduction in transportation costs for the affected miles traveled can be anticipated. Also, many other mass transit improvement strategies exist, but no cost estimates have been developed. Depending upon the effectiveness of the alternative means, some penalties in convenience can be expected, although some improvements could be possible.

Table III-13 lists those AQCR's for which implementation plans include transportation controls and whose plans have promulgated at this time. Implementation of these plans will be completed in the 1975-77 time interval. Also shown in the table are the specific control measures under consideration.

Total costs for state-imposed transportation controls are indefinite at this time; however, for those AQCR's listed in Table III-13, more than 20 million vehicles are affected and an estimated $2 billion may be required for implementation through 1979. About half of this will be for retrofit equipment and half will be accumulated costs of inspection and maintenance (I/M) programs and service-station vapor controls. This total will, of course, be larger when additional state implementation plans are analyzed to determine their costs.

AIRCRAFT EMISSION CONTROLS

Aircraft emissions have been identified as significant contributors to the regional burden of pollution in comparison to other sources which will have to be controlled to meet National Ambient Air Quality Standards.

Airports are concentrated sources of pollutant emissions which will in many cases reduce local air quality to unsatisfactory levels even though emissions from automobiles and stationary sources are within acceptable levels within the general area. That is, unless aircraft emissions are reduced, airports will still remain intense area emitters of pollutants even after emissions from other area sources have been greatly reduced.

The Clean Air Act directs the Administrator of the EPA to "establish standards applicable to emissions of any air pollutant from any class or classes of aircraft or aircraft engines which in his judgment cause or contribute to air pollution which endangers the public health or welfare". In July, 1973, Federal emission standards and test procedures were established for various classes of new and in-use aircraft engines (III-14). These regulations are based on the need to control emissions occurring under 3000 feet to protect ambient air quality in urban areas. However, the standards are not quantitatively derived from the air quality considerations in affected areas but, instead, reflect EPA's judgment as to the emission levels that will be practicable with present and projected technology. The requisite technology is assumed to include advanced combustion-system concepts for turbine engines and improved fuel systems for piston engines.

The standards cover (a) fuel venting regulations beginning January 1, 1974, (b) smoke emission regulations taking effect in 1974, 1976, and 1978 for various engine classes, and (c) gaseous emission (CO, HC, and NO_x) standards for 1979 and 1981. Gaseous emissions regulations are based on a simulated landing-and-takeoff operating cycle which includes (1) taxi/idle (out), (2) take-off, (3) climb-out, (4) approach, and (5) taxi/idle (in). Piston engines are included in the standards beginning in 1979.

In general, the influence of the regulations will be to contribute to the maintenance of the quality of the air in and around major air terminals throughout the post-1979 era in which air traffic is undergoing expansion. The timing of these standards is such that they will not make contributions to achievement of ambient air-quality levels required by 1975 through the state implementation programs.

Present aircraft emission standards and their estimated cost impact are listed in Table III-14. Costs of fuel venting and smoke-emission controls through 1978 totaling $17 million are minor in comparison to costs of controlling other sources in that time period.

TABLE III-12 CONTEMPLATED IN-USE-VEHICLE EMISSION CONTROL MEASURES AND ASSOCIATED UNIT COSTS

Control Measure	Model Year Applicability	Estimated Pollutant Reduction, percent			Estimated Cost in Year of Implementation
		HC	CO	NO_x	
Inspection/Maintenance (I/M) Programs	All years	11	10	--	$1.20 - 31.20(a)
Retrofit (Vacuum Spark Advance Disconnect) (VSAD)(b)	Pre-1968	25	9	23	$30
Retrofit (Air Bleed)	Pre-1968	21	58	0	$56 - 64
Retrofit (Catalyst)	1968-74	68	63	48	$90 - 140
Service Station Vapor Control	All years	n/a	n/a	n/a	$ 3.20(c)

Source: EPA, Reference III-11.

(a) Range of costs reflects the fact that some cars will require maintenance, others will not.

(b) Including lean idle air/fuel adjustment.

(c) Assuming the average cost per car of controlling service station vapor emissions is passed on to the consumer over a 5-year period.

TABLE III-13. AQCR'S WITH TRANSPORTATION CONTROL PLANS

AQCR	Control Measure
Alaska	
Fairbanks	VMT, I/M, Air Bleed, Catalyst
Arizona	
Phoenix-Tucson	VMT, I/M, Air Bleed, Catalyst
California	
Los Angeles	VMT, I/M, VSAD, Catalyst, Service Station
Sacremento	VMT, I/M, VSAD, Catalyst, Service Station
San Diego	VMT, I/M, VSAD, Catalyst, Service Station
San Francisco	VMT, I/M, VSAD, Catalyst
San Joaquin Valley	VMT, I/M, VSAD, Catalyst, Service Station
Southeast Desert	VMT, I/M, VSAD, Catalyst, Service Station
Colorado	
Denver	VMT, I/M, Air Bleed, High Altitude Mod., Service Station
National Capital (Metro. D.C., Md., Va.)	VMT, I/M, VSAD, Catalyst, Air Bleed
Illinois	
Chicago	VMT, I/M
Indiana	
Indianapolis	I/M, Service Station
Maryland	
Baltimore	VMT, I/M, VSAD, Air/Fuel, Catalyst, Service Station
Massachusetts	
Boston	VMT, I/M, VSAD, Air Bleed, Catalyst, Service Station
Springfield	VMT, I/M
Minnesota	
Minneapolis-St. Paul	VMT
New Jersey	VMT, I/M, Exhaust Gas Recirculation, Catalyst, Service Station
New York	
New York (Metro. NYC: NYC, Conn., N.J.)	VMT, I/M, VSAD, Air Bleed, Catalyst
Rochester	I/M
Ohio	
Cincinnati	I/M
Oregon	
Portland	VMT, I/M, Air Bleed
Pennsylvania	
Metro. Philadelphia Interstate	VMT, I/M, Air Bleed, Service Station
Southwest Pennsylvania Interstate	VMT, I/M, Air Bleed, Service Station
Texas	
Austin-Waco	VMT
Corpus Christi	VMT
Dallas-Ft. Worth	VMT, Service Station
El Paso	VMT, Service Station
Houston-Galveston	VMT, I/M, VSAD, Service Station
San Antonio	VMT, I/M, Service Station
Southeastern Texas - Southern Louisiana	VMT
Utah	
Wasatch Front (Salt Lake City, Provo, Ogden)	VMT (Salt Lake City), I/M, Air Bleed, High Altitude Modification
Washington	
Seattle-Spokane	VMT, I/M, Air Bleed, Exhaust Gas Recirculation

Sources: EPA, References III-13 and III-14.

Definitions Used in Table:

"VMT" - Measures to reduce Vehicle Miles Traveled
"Service Station" - Gasoline vapor control at service stations
"I/M" - Inspection and Maintenance of motor vehicles
"VSAD" - Vacuum Spark Advance Disconnect Retrofit
"Catalyst" - Catalyst Retrofit
"Air Bleed" - Air Bleed Retrofit
"High Alt. Mod." - High Altitude Modification
"Exhaust Gas Recirculation" - EGR Retrofit
"Air/Fuel" - Air/Fuel Control Retrofit

The estimated cost of development and recertification efforts for compliance with the 1979 gaseous-emission standards is $65 million, and the additional engine-hardware costs which will be incurred in 1979 is estimated to be $3.5 million. No fuel-consumption penalties are expected to result from the 1979 standards. The 1981 standards will, of course, have had no cost impact within the time period of concern in this report.

The 1979 standards promulgated for piston-type aircraft are expected to result in significant fuel savings: $29 million over 10 years. No credit for these savings has been assumed in estimating the cost of aircraft emission control.

In total, cumulative national costs through 1979 for aircraft emission control are expected to total approximately $85 million.

HEAVY-DUTY VEHICLE CONTROLS

Separate emission-control regulations have been in effect since 1970 for new heavy-duty gasoline and diesel truck engines manufactured for use in over-the-highway trucks and buses of over 6000 lb GVW. Trucks under 6000 lb GVW are considered light-duty vehicles and have been dealt with in a previous section of this report.

Heavy-duty-truck engine-certification procedures are performed on the engine itself and do not pertain to the vehicle as do light-duty truck and passenger car regulations.

Consideration is being given by EPA to the need for establishing a medium-duty truck category which would cover vehicles in the range from 6,000 lb to 10-14,000 lb GVW weight class. However, at present, no such regulations have been formally proposed by EPA.

Heavy-Duty Gasoline Engines

Federal regulations for emissions from heavy-duty gasoline engines are shown as Table III-15. For 1970 through 1973, regulations covered HC and CO emissions only measured in terms of average concentration in the engine exhaust over a constant-speed, variable-load dynamometer cycle. For 1974, new standards are in effect which are based on the same test procedure, but in which emissions are reported in terms of average grams per horsepower hour. The sum of HC and NO_x emissions are limited to 16 g/hp-hr while the standard for CO is 40 g/hp-hr.

Year	Standards	Implementation Technology	Estimated Cost of Implementation, by 1979
1974	JT8D smoke standards	Combustor and fuel nozzle retrofit	None (already voluntarily completed)
1974	Fuel venting restrictions for new and in-use engines (1975 for business-aircraft engines)	Plumbing and/or operational changes	$2 million
1976	Smoke standards, new turbine engines except JT3D, JT8D, and supersonic		None
1978	JT3D smoke standards	Fuel nozzle retrofit	$15 million
1979	Gaseous emission(HC, CO, and NO_x) standards for all engines manufactured	Modified engine hot section	$68 million(a,b)
1981	Gaseous emission standards for newly certified engines	Advanced combustor and engine concepts	None by 1979
1979 Total			$85 million(b)

Sources: EPA, References III-14 and III-15.

(a) Principally development and recertification costs. Includes additional engine hardware costs which will be incurred in 1979. Maximum additional engine cost estimate to be:

$10,000	per large turbine engine
6,000	per small turbine engine over 8000 lb thrust
2,000	per small turbine engine under 8000 lb thrust, and per turboprop or APO engine
52	per piston engine.

(b) Estimated $29 million in piston engine fuel savings is not included.

TABLE III-15. FEDERAL STANDARDS FOR HEAVY-DUTY GASOLINE-ENGINE EMISSIONS(a)

Pollutant	Emission Standards(b)	
	1970-73(c)	1974
Hydrocarbons	275 ppm	HC + NO_x:
Oxides of nitrogen	--	16 g/hp-hr
Carbon monoxide	1.5 percent	40 g/hp-hr

(a) For use in vehicles of more than 6,000 lb GVW designed primarily for transportation of property or having a capacity of more than 12 persons.

(b) Emissions averaged over a 9-mode, 300-sec, constant speed dynamometer cycle.

(c) 1973 California standards were equivalent to 1974 Federal standards for heavy-duty engines.

The emission control technology used for heavy-duty gasoline engines through 1973 is similar to that employed for light-duty trucks and passenger cars through the 1972 model year. In fact, many heavy-duty gasoline engines are derivatives of passenger-car engines. For 1974, the NO_x control standards are generally attainable without the use of EGR, although some EGR engines were certified in the previous year to meet California standards for 1973 which were at the same level as Federal standards for 1974.

No detailed equipment-cost estimates have been made by EPA for heavy-duty gasoline truck engine emission controls. In the absence of such estimates, it is assumed for purposes of this report that the per-vehicle cost increment of 1970-73 engines is equivalent to that for 1970 model year passenger-car engines less the cost of fuel evaporation controls, or $21.50. It is further assumed that the 1974 and following-year control equipment costs will be equivalent to that for a 1973 passenger car engine less the cost of EGR and evaporative controls, or $45.50.

Incremental annual maintenance costs for heavy-duty gasoline truck controls for all years are assumed to be the same as passenger-car costs, or $16.

Fuel consumption penalties are estimated to be 3 percent for 1970-73 and 5 percent for 1974 and beyond. Estimate of total per-vehicle costs attributable to emission controls for this class of trucks are summarized in Table III-16.

TABLE III-16. ESTIMATED PER-VEHICLE COST PENALTIES FOR HEAVY-DUTY GASOLINE ENGINE EMISSION CONTROL

Incremental Cost Item	Model Years	
	1970-73	1974-79
Emission-control equipment cost	\$21.50	\$45.50
Annual maintenance	\$16.00	\$16.CO
Fuel consumption penalty	3 percent	5 percent

Population projections for controlled heavy-duty gasoline trucks are shown as Figure III-2. It is estimated that the population of 1970-73 trucks of this class will peak at about 4.5 million in 1973 and that the total controlled population will have reached approximately 8.5 million in 1979.

Total estimated annual costs for heavy-duty gasoline truck Federal emission controls are presented as Table III-17. The cumulative total for the 1970-79 interval is \$1.9 billion.

Heavy-Duty Diesel Engines

Heavy-duty truck diesel engine Federal standards are shown as Table III-18. Through 1970-73, standards covered smoke emissions only. In 1974, the standards were revised to include HC, NO_x, and CO emissions as well as more stringent smoke emissions. The permissible gaseous-emission levels are the same as for heavy-duty gasoline engines for 1974 but the test procedure is different. For diesels, emissions are averaged over a 13-mode, variable-speed, variable-load dynamometer cycle.

Both smoke and gaseous emission standards including those for 1974 have been attainable largely through fuel-injection-system modifications. (NO_x and smoke are the more difficult emissions to control; even uncontrolled diesels are usually well within CO standards.) Equipment cost penalties are considered nominal; further, it is estimated that no fuel consumption penalties have been incurred. Accordingly, no national cost penalty is attributed to diesel-truck engine emission controls.

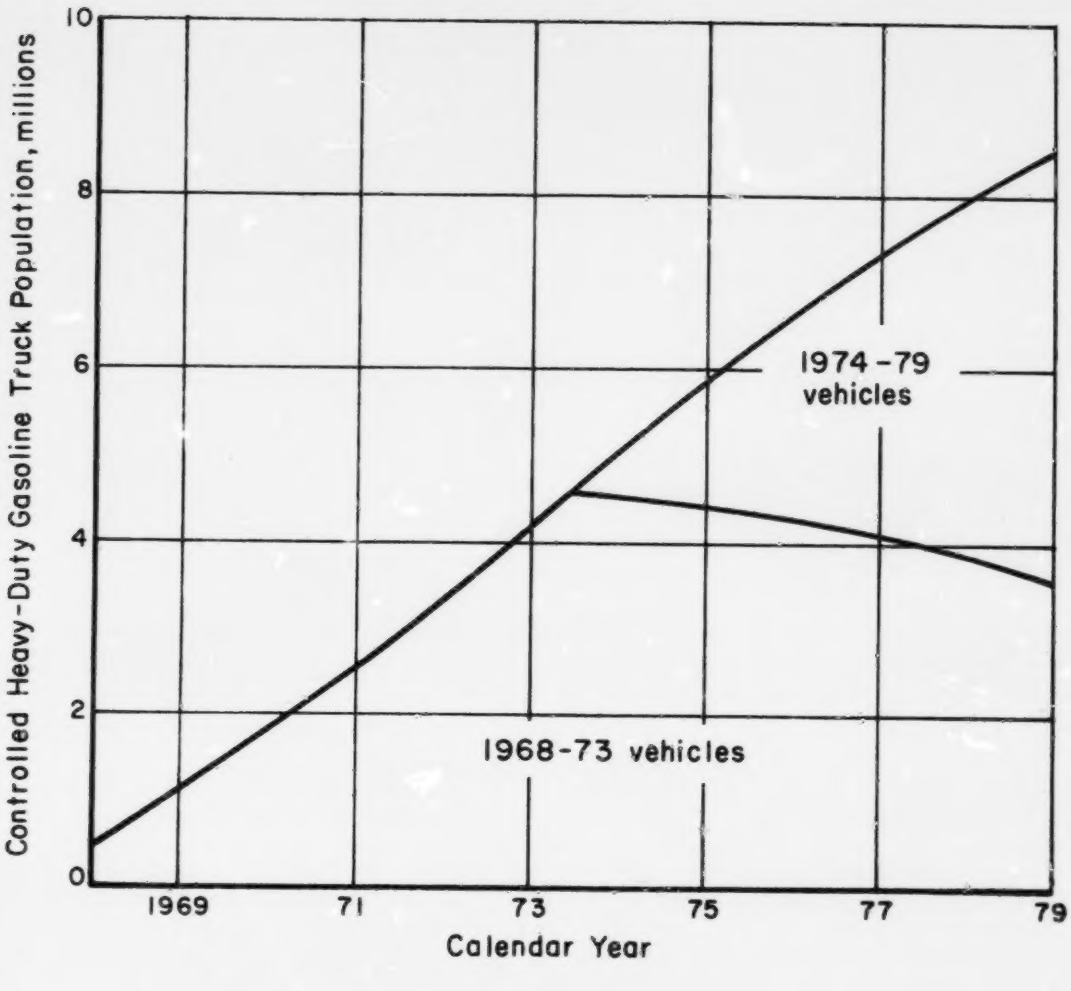

FIGURE III-2. PROJECTED POPULATION OF HEAVY-DUTY GASOLINE-ENGINE TRUCKS

TOTAL NATIONAL COSTS FOR FEDERAL MOBILE-SOURCE EMISSION CONTROLS

Table III-19 summarizes the total national costs attributable to Federal regulations controlling mobile-source emissions for the period 1968-1979. The $57.3 billion light-duty emission control costs substantially surpass other mobile-source costs in this time period. Total cumulative costs for mobile-source controls are estimated to be $61.3 billion.

TABLE III-17. ESTIMATED NATIONAL COSTS FOR HEAVY-DUTY GASOLINE-ENGINE EMISSION CONTROLS

Cost Item	Annual National Cost, $ millions									
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Equipment	14	14	17	23	39	39	39	39	39	39
Maintenance	0	7	18	30	46	61	74	86	98	108
Fuel-consumption penalties	8	20	37	63	92	123	154	184	212	239
Annual total, $ millions	22	41	72	116	117	223	267	309	349	386
Cumulative total, $ millions	22	63	135	251	428	651	918	1,227	1,576	1,962

TABLE III-18 FEDERAL STANDARDS FOR HEAVY-DUTY DIESEL ENGINE EMISSIONS(a)

Pollutant	Emission Standard 1970-73(b)	Emission Standard 1974
Smoke		
Percent opacity in accelerating mode	40	20
Percent opacity in lugging mode	20	15
Peak opacity in either mode	--	50
HC + NO_x, g/hp-hr(c)	--	16
CO, g/hp-hr(c)	--	40

(a) For use in vehicles of more than 6000 lb GVW designed primarily for transportation of property or having a capacity of more than 12 persons.

(b) 1973 California standards were equivalent to 1974 Federal standards for heavy-duty engines.

(c) Emissions averaged over a 13-mode dynamometer cycle.

TABLE III-19. ESTIMATED NATIONAL COSTS FOR MOBILE-SOURCE EMISSION CONTROL 1970-1979

Cost-Increment Category	Annual National Cost, $ billions										
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Year Not Specified
Federal light-duty vehicle emission control	1.66	1.44	2.10	3.65	4.62	7.24	7.89	8.99	9.55	10.15	
Federal heavy-duty vehicle emission control	0.022	0.041	0.072	0.116	0.117	0.223	0.267	0.309	0.349	0.386	
State transportation controls											2.00
Federal aircraft emission controls											0.085

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IV. INDUSTRIAL SOURCE CONTROL COSTS

INTRODUCTION AND SUMMARY

Industrial Sources Included

The industrial sources covered in this report are basically the same as those covered last year. They represent the large and identifiable sources which are judged to represent the major elements of the total industrial cost of control. These industries are grouped into six groups, as shown in the following list.

Fuel Industries Group

- Coal Cleaning
- Natural Gas Processing
- Petroleum Industry

Chemical Industries Group

- Carbon Black
- Chlor-alkali
- Nitric Acid
- Phosphate Fertilizer
- Sulfuric Acid

Metals Industries Group

- Ferroalloy Industry
- Foundries (Iron)
- Foundries (Steel)
- Iron and Steel
- Primary Aluminum
- Primary Beryllium
- Primary Copper
- Primary Lead
- Primary Mercury
- Primary Zinc
- Secondary Aluminum
- Secondary Brass and Bronze
- Secondary Lead
- Secondary Zinc

- Burning and Incineration Group
  - Dry Cleaning
  - Sewage Sludge Incineration
  - Solid Waste Disposal
  - Teepee Inincerators
  - Uncontrolled Burning
    - Agricultural
    - Coal Refuse Burning
    - Forest Fires
    - Structural Fires
- Quarrying and Construction Group
  - Asbestos Industry
  - Asphalt Concrete Industry
  - Cement Industry
  - Crushed Stone; Sand; and Gravel
  - Lime Manufacture
- Food and Forest Products Group
  - Feed Mills
  - Grain Handling
  - Kraft Paper Industry
  - Semichemical Paper Industry

Coal refuse burning and teepee incinerators are included in the functional Burning and Incineration Group instead of in the Fuel Industries and Food and Forest Products Groups, respectively.

Emission Estimates

For each industrial source category two sets of emission levels have been calculated: (1) the level of emission of each pollutant with pollution control equal to that exercised prior to the Clean Air Act of 1970, and (2) with control exercised in accordance with standards set under the provisions of that Act. In the emissions tabulations in Chapter IV, the former is identified by the words "without further controls", and the latter by the words "with further controls". These standards are provided in the State Implementation Regulations to achieve ambient air-quality levels for the six critical pollutants for which criteria have been established, New Source Performance Standards, and Hazardous Materials Emissions Standards.

Future airborne industrial emissions levels will be affected by the growth of the industry in question, together with the control achieved over the process emissions. Growth of industrial emissions for the next 5 years can be extrapolated with a fair degree of confidence from trends in the past 5 years, when technological innovations are not involved. In those industries where new source performance standards have been set up at significantly more stringent emission limitations than existing sources, the contribution of growth to total emissions becomes less significant.

In addition to industry growth, changes in production methods affect emission levels. The steel industry, for example, exhibits an internal trend whereby open-hearth production is decreasing, while production by the less polluting basic oxygen process and electric arc processes are increasing. Available data on shifting percentages of production, as in the steel industry, were included in the analysis when different modes of production yield different emission levels.

The magnitude of industrial output for each industry studies was projected through the 1975-1979 period, on the basis of 1970 output and growth rate. The levels of emission in 1979, with and without additional control, are given in each of the following industry discussions.

Control Cost Estimates

For each industry or industrial operation listed above, the estimated total investment cost (in constant 1973 dollars) for air pollution control equipment in the 5-year period FY 1975 through FY 1979 was presented in Table I-2. The cumulative estimated total investment costs (in constant 1973 dollars) for the 9-year period FY 1971 through FY 1979 were presented in Table I-1. These estimated investment costs include the normal capital charges associated with the installation of emissions control systems. These charges include estimates of the costs of site preparation, equipment purchase, transportation, equipment installation, process hookup and modification where applicable, and any required auxiliary systems. Where appropriate or known, a standard allowance was made for construction loan interest, engineering charges, and similar capital expenses. The capital cost of emissions monitoring equipment was included only on those special cases where such costs were well-defined and known to the process analyst.

Estimated annualized costs (sometimes used interchangeably with the ten annual costs) associated with the estimated capital investments in the two time periods of interest also are shown in Tables I-1 and I-2 and in each of the following industry sections. These estimated annualized costs are presented for only the last year of the period (FY 1979) to reflect the cost per year to each industry after all air pollution abatement equipment has been installed. The annualized costs reflect interest and depreciation-related charges through the use of a capital recovery factor based on the known or estimated life of the chosen emissions-control systems and upon the assumption of a uniform interest rate of 10 percent per annum. The estimates of annualized costs include estimates of operating and normal maintenance charges, but do not include additional charges for operating emissions-monitoring equipment.

Capital and annualized costs for equipment installed prior to FY 1971 were not included. The costs associated with any required process modifications judged attributable to the implementation of the requirements of the Act were included.

Cash requirements for each industry were estimated for each of the two time periods of interest. The estimate of cash requirements includes the following items:

- estimated total investment requirement for the period
- estimated interest expense (at 10 percent per annum) for all years
- estimated total net operating and maintenance charges for the period, after any byproduct credits have been taken.

Cash requirement is an approximation of the total amount of cash that will be required during the period in order to implement required emissions-control regulations.

It should also be noted that in the course of constructing model plants for industries contained in this report, the computation of unit cost has, in some instances, been based on dollars per unit of capacity (rather than dollars per unit of production). This was done in cases where capacity figures were more readily available than production numbers. Consequently, the user must, if unit production costs are desired, scale down the capacity numbers himself. It is anticipated that unit costs in the 1975 Cost of Clean Air will be defined for all industries in terms of dollars per unit of production.

FUEL INDUSTRIES GROUP

Coal Cleaning

Introduction and Summary

Nature of the Product and Process. In the mining of coal, various inert materials and other impurities such as pyritic sulfur are recovered along with the coal which, if present in quantity, must be removed. Approximately 50 percent of the marketed coal is mechanically cleaned.

In 1971, 328 million metric tons of raw coal were cleaned recovering 246 million metric tons of coal and removing 82 million metric tons of refuse. Because of the mechanical cutting and loading methods used in underground coal mining about 70 percent must be mechanically cleaned. In strip mining, in which the coal seams are uncovered, impurities are much lower so that only 30 percent requires cleaning.

The cleaning of coal by physical means involves methods similar to the separation of solids in ore-dressing industries. Wet-processing methods are used for about 95 percent of the coal that is mechanically cleaned; pneumatic (air cleaning) methods account for the other 5 percent. While particulate emissions from pneumatic cleaners are relatively low, dust-abatement regulations of the Occupational Health and Safety Act will require a higher moisture level inhibiting air table operations, so it is assumed that cleaning by this method will be discontinued by 1975.

In order to reduce the moisture content of coal to satisfactory levels following wet-process cleaning, thermal drying may be required. In 1971, there were 103 thermal-drying plants processing almost 45 million metric tons of coal.

Emissions and Control Costs. In order to meet New Source Performance Standards on particulate emissions, venturi scrubbers (or the equivalent) will be required. Emissions without controls are estimated at 280,000 metric tons in FY 1971, and the controlled emissions are estimated at 62,000 metric tons. In FY 1979, controlled emissions are estimated at 3400 metric tons.

Installation of these controls is estimated to require an investment of $16 million. The estimated annualized cost associated with this investment is $3.3 million. Cash requirements are estimated at $27.5 million for the period FY 1971 through FY 1979.

Industry Structure

Characteristics of the Firms. Almost one-half of all bituminous coal mined in the United States in 1971 was produced by the top 15 coal company groups. This represents a gain of 8.6 percentage points since 1961. All of the producing groups have increased production substantially over the 10-year period. During the same time period, the character of the coal mining industry has been shifting to both fewer mines and a greater dependency on stripping operations.

In 1961, the Bureau of Mines listed a total of 7,648 mines operating in the United States. Of these 5,843 were underground mines, 1,477 were strip mines, and 328 were auger operations.

By 1971, the number of operating mines had dropped to 5,149. Of this number, 2,268 were underground mines; 2,290 were strip mines, and 591 were auger mines. This large decrease in the number of underground mines is a direct result of the 1969 Coal Mine Health and Safety Act which placed strict regulations on underground operations. Increasing constraints on stripping operations will also affect the growth in coal production and the character of coal-mining operations over the next several years.

Large mines account for a majority of the total coal produced. In 1971, there were 152 underground mines having an annual output of 454,000 or more metric tons of bituminous coal. In total, these mines produced 138 million metric tons of coal. There were 104 strip mines producing 454,000 metric tons per year or more, and these mines produced a total of 94 million metric tons. Together, these 256 large mines produced almost half of the coal mined in 1971.

On the other hand, there was a total of 1,600 mines operating in 1971 with annual outputs less than 9,200 metric tons. These mines produced only 7.1 million metric tons of coal, not much more than the output of the largest producing mine in the U.S. in 1971.

In 1961, 65.7 percent of the bituminous coal mined in the U.S. was mechanically cleaned to reduce the ash and sulfur components of the coal. In 1971, a much smaller percentage, 49.1 percent, was mechanically cleaned. This decline has resulted from expanded strip-mine operations, in which less foreign matter is present and from increased shipments to electric utilities, who traditionally have bought coal on a price-per-million Btu basis and who have furnaces capable of handling unwashed coals.

Coal Cleaning (Preparation). The primary objective of mechanical cleaning is to upgrade the quality of the coal. Activities include: (1) crushing and sizing in accordance with requirements of the market, (2) removal by physical separation of as much of the noncoal and other ash-forming mineral constituents as possible economically without excessive loss of coal substance, (3) removal of as much pyritic sulfur as possible concurrent with (2), and (4), removal of mineral matter and sulfur by special chemical treatment, which represents an area of current research rather than current practice.

The cleaning of coal by physical means involves methods similar to separation of solids in the ore-dressing industry. Generally, these utilize washing methods based on the differences in specific gravity between the impurities (including removable forms of sulfur) and the main constituents of coal. Coal cleaning has been carried out for the past several decades using such techniques singly or in combination. In 1971, the percentages of coal cleaned by type of equipment was as follows:

Process	Percentage
Jigging	42.5
Dense-Medium	33.2
Tabling	13.1
Pneumatic	5.3
Classifier	0.8
Launder	1.8
Flotation	3.3
Total	100.0

All of these but the pneumatic (air) methods are "wet" methods. Much of the cleaned coal is shipped wet and often mixed with salt or oil to minimize freezing in the winter months. About 18 percent of mechanically cleaned coal is thermally dried before loading. Drying is practiced for one or more of the following reasons: (1) to avoid freezing difficulties and to facilitate handling during shipment, storage, and transfer to points of use; (2) to maintain high pulverizer capacity; (3) to reduce heat loss due to evaporation of surface moisture from the coal in the burning process, thus increasing heating efficiency; (4) to improve the quality of the coal used for special purposes, such as production of coke, briquettes, and chemicals; and (5) to decrease transportation costs.

Particulate emissions from coal-drying operations are the major source of air pollution from coal-cleaing plants.

Current Capacity and Growth Projections. The capacity of coal-cleaning plants is impossible to calculate precisely because data concerning individual plants or mines are not specific. The U.S. Bureau of Mines lists the number of thermal-drying plants and quantity dried by state permitting an estimated distribution of plant sizes by state from which model plant sizes were developed. In 1971, production of thermally dried coal was 43.6 million metric tons.

A basic factor inhibiting the rapid growth of coal production is the high sulfur content of most readily available Eastern coals. Low-sulfur coals exist both in the Eastern and Western sectors of the nation; however, most of these Eastern coals are coking coals and little excess capacity exists. A great potential of untapped low-sulfur coal reserves exists in the West, but the high cost of transporting these coals to Midwest and

Eastern markets has, until recently, precluded large-scale consumption. Major factors affecting the future of the domestic coal industry are listed as follows:

- Air-pollution regulations relating to SO_2 emissions from coal-buring power plants cannot be met in 1975 without the widespread use of SO_2 stack-gas control devices or very rapid, and perhaps unachievable, increases in strip mining in Western states.
- Only with widespread availability of SO_2 control devices and substantial reductions in their costs (50 percent below current estimates) can Eastern and Midwestern strip-mined coal maintain a competitive position versus Western low-sulfur strip-mined coal
- Widespread availability of combined-cycle power plants and the availability of low-Btu (and possibly medium-Btu) coal gasification can offer significant opportunities for Eastern coals in Eastern markets
- Without significant cost reduction, high-Btu gasification of coal will not find substantial application in energy delivery systems to electric utilities
- Due to the small contribution of the costs of coal washing or preparation, decreases in unit costs (or increases in efficiency) will have little impact upon the utilization of coal
- From the point of view of the overall costs of supplying fossil fuels, the most economically attractive locations for expansion of mining capacity is in the West.

The recently announced policy of prohibiting the wide-scale conversion of coal-fired electric power plants to oil should have a beneficial effect on the coal industry, if implemented.

Based on this background, an overall projection of an annual 4 percent growth rate in the coal industry to 1979 has been used. It is also assumed that there will be an equivalent growth rate in the demand for mechanical cleaning and thermal drying of coal. Strict adherence to air quality regulations or sulfur oxides emissions limitations would slow the growth in demand for coal considerably. On the other hand, restrictions on imports of petroleum will lead to an accelerated demand for coal.

Emission Sources and Pollutants

The particulate emissions of primary concern from coal-cleaning plants are generated in the drying operation. The dryer is simply a device in which hot flue gases and air are used to heat the wet cleaned coal, evaporate much of the moisture, and transport the water vapor out of the system. This simple principle becomes quite complex because of the large weight of materials that must be handled on a continuous basis.

New Source Performance Standards will require a substantial reduction in particulate emissions from coal-cleaning operations. The major emission sources are thermal dryers and pneumatic cleaners. Typical uncontrolled emission factors are 2.5 kg per metric ton of dried coal from flash dryers, 6.5 kg per metric ton from fluidized-bed dryers, and 0.09 kg per metric ton from pneumatic cleaners.

Available data on the level of present control indicate that 87 percent of the thermal dryers are controlled to an efficiency of 90 percent. An additional 1 percent is controlled to an efficiency of 99 percent. The remaining dryers are assumed to be uncontrolled. To meet New Source Performance Standards, it is assumed that venturi scrubbers will be added to thermal dryers.

For pneumatic operations, 57 percent of capacity was controlled in 1971, resulting in total emissions of 1655 tons. The future use of pneumatic cleaning of coal is in doubt. To meet the dust-abatement regulations of the Occupational Health and Safety Act will require a high moisture content in the coal that will inhibit operation of air tables. Under these constraints, it is assumed that no pneumatic cleaners will be constructed and that existing operations may have to be discontinued.

Estimated controlled and uncontrolled particulates emissions from coal-cleaning operations (in thousands of metric tons) are as follows:

Fiscal Year	Mode	Particulates
1971	Without Control	280
	Without Further Control	62
1975	Without Control	365
	With Further Control	2.9
1979	Without Control	430
	With Further Control	3.4

Control Technology

Operators have traditionally relied on low-energy cyclones to recover fines from the dryer and to reduce emissions. The overall collection efficiency of these devices is about 90-95 percent. Cyclones alone are not capable of the high collection efficiency required to meet the 0.03 gr/dscf proposed Federal standard. The selection and design of the cyclone is normally confined to providing the most economic product recovery consistent with the lowest maintenance and operating costs. Typical emissions from a cyclone range from 0.5 to 15 gr/dscf, averaging about 4 gr/dscf.

Baghouses or high-energy wet scrubbers are generally required by industrial process operators to meet strict air pollution regulations on particulate emissions. Bag filters are not applicable for coal-cleaning operations because of the susceptibility to fire and explosion, and high bag-replacement cost. Gas inlet temperature to the filter must be kept above the dew point to prevent the formation of a mud which will blind the filter. This is particularly difficult on dryer effluents, where the dew point of the exit gas approaches the gas temperature. For these reasons, bag filters are seldom used in coal-cleaning operations.

Currently, the most applicable wet scrubber for coal-cleaning operations is the venturi. This scrubber type is virtually free from the plugging problems which plague other scrubber types. Also, the scrubbing liquid can be recirculated--thus, keeping water usage to a minimum. The venturi provides the highest collection efficiency when operated at high-pressure drop. The major disadvantage of the venturi scrubber is the high operating cost when a high-pressure drop is required across the throat section.

The estimated cost of meeting New Source Performance Standards for coal-cleaning plants is based on the investment and annual costs of installing venturi scrubbers on thermal dryers. Investment, annualized, and unit costs for controls on selected model plants are shown in Table IV-1. It is estimated that the costs are approximately the same for new and existing plants.

Estimated investment and annual costs for installing control equipment on existing coal-cleaning plants and new facilities for the period FY 1971 to FY 1975.

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	12.52	11.52	13.70
Annual Costs			
Capital Charges	1.47	1.38	1.58
Operating and Maintenance	1.16	1.09	1.23
Total Annual Costs	2.63	2.47	2.81
Cash Requirements	22.05	20.80	23.56
New Facilities			
Investment	3.24	2.98	3.52
Annual Costs			
Capital Charges	0.38	0.35	0.41
Operating and Maintenance	0.31	0.29	0.32
Total Annual Costs	0.69	0.65	0.73
Cash Requirements	5.42	5.08	5.78

TABLE IV-1. COSTS OF CONTROL FOR MODEL PLANTS IN THE COAL-CLEANING INDUSTRY

Model Size, metric tons/day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/annual metric ton[(a)]		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
91	80.4	63.2	105.5	15.08	11.84	19.69	0.66	0.52	0.87
363	248.6	213.3	285.5	51.23	45.02	57.45	0.56	0.50	0.63
544	360.5	329.0	393.3	77.48	70.43	84.19	0.56	0.51	0.62
910	558.6	508.4	610.9	125.76	114.80	137.02	0.55	0.51	0.61

(a) Dollars per metric ton of annual capacity, based on a 250-day operation.

Natural-Gas Processing Plants

Introduction and Summary

Nature of the Product and Process. Natural gas, which is largely composed of methane, is often discovered in association with other hydrocarbons and may contain varying quantities of other gases such as carbon dioxide, nitrogen, helium, and hydrogen sulfide. The liquid hydrocarbons are separated, and other gases must often be removed in order to obtain a natural gas of pipeline quality. Because of the corrosive qualities, odor, and poisonous nature of hydrogen sulfide, it must be reduced to very low levels. About 8 percent of the natural gas produced in the United States requires some form of treatment for removal of hydrogen sulfide. Hydrogen sulfide in this sour natural gas may vary from trace quantities to a high of 75 percent by volume of the natural gas.

Where hydrogen sulfide is present in sufficient quantity to justify economic recovery, Claus plants have been installed. In other plants, hydrogen sulfide has been separated from the natural gas and flared to the atmosphere as sulfur oxides. In order to meet the 1975 air-quality standards, it will be necessary to install Claus plants (or equivalent control processes) in natural-gas processing plants presently flaring the hydrogen sulfide and to install tail-gas scrubbers on all Claus plants to reduce sulfur emissions to acceptable levels.

Emissions and Control Costs. In FY 1971 emissions of sulfur oxides from processing plants containing Claus units are estimated to be 184,000 metric tons per year, and uncontrolled emissions from other plants are estimated to be 852,000 metric tons per year. These uncontrolled emissions are estimated to be about the same in FY 1979. In contrast, controlled emissions would be about 20,000 metric tons in FY 1979.

Control costs from FY 1971 to FY 1979 are estimated to require an investment of $90 million, with an associated annualized cost of $27.3 million.

Industry Structure

Characteristics of the Industry. The natural gas industry may be viewed as having two major elements: production and transmission/distribution. The production sector is dominated by large firms but with many smaller firms contributing a sizeable share of the total output. The transmission/distribution sectors are primarily organized as public utilities, operating under Federal and/or state regulations. Although many gas utilities are now integrating back to production, the basic structure remains. Processing plant operations are a necessary part of the production sector in providing a natural gas suitable for pipeline transmission.

While the vast majority of natural gas fields discovered in the United States contain little or no hydrogen sulfide (H_2S), a sizeable number of gas fields in the United States contain hydrogen sulfide in quantities requiring treatment. A much smaller number of fields have hydrogen sulfide in sufficiently large quantities to warrant the recovery of elemental sulfur from the natural gas. A breakdown of the ownership of Claus plants for sulfur recovery from natural gas is as follows:

Company	Percentage Share of Capacity
Shell Oil	25
Amoco Oil	16
Humble Oil (Exxon)	9
Getty Oil	6
Cities Service	5
Warren Petroleum	5
Phillips Petroleum	4
Other Oil Firms	5
Other Firms (Chemical or Natural Gas Producers)	25
Total	100

In addition to these plants, there are other natural gas plants that remove and incinerate the small quantities of H_2S contained in the natural gas, releasing SO_2 to the atmosphere. A listing of these plants is not available. Emissions and cost of control from these plants have not been estimated in the past.

Current Capacity and Growth Projections. No reliable data are published on the total amount of sulfur recovered annually from natural-gas plants. Based on published figures for the average daily sulfur recovery from 20 specific plants, an equipment-utilization factor of 63 percent was computed. This operation level was assumed for the entire industry.

It is difficult to estimate the required increase in Claus plant or equivalent capacity that may be required to remove the hydrogen sulfide from natural gas. Most projections of natural gas supply assume little or no increase over the next several years. While many new fields may be discovered in the Southwest United States, on the Gulf coast both on-shore and off-shore, in the Rocky Mountain Area and elsewhere, it has been assumed that the capacity of these plants will remain essentially constant through FY 1979.

Emission Sources and Pollutants

Natural Gas Plants Without Claus Units. Emissions from these plants have not been considered in the past. The emissions from any given plant are a function of the sulfur content of the gas feedstock. Hydrogen sulfide is reduced to acceptably low levels in amine scrubbing units or equivalent treatment methods. The hydrogen sulfide recovered from the amine solution is then converted to sulfur oxides by flaring, with subsequent release to the atmosphere. In 1972, EPA estimated the daily sulfur oxides emissions from these plants to be 852,000 metric tons per year. The installation of a Claus unit capable of 94 percent sulfur recovery efficiency would lower these emissions to 55,000 metric tons per year. The addition of a tail-gas scrubber to the Claus unit would further lower overall emissions to 4500 metric tons per year.

Natural Gas Plants With Claus Units. Based on the assumption of a 94 percent sulfur recovery factor, the emissions from these plants at 63 percent operating capacity would total 184,000 metric tons per year. The installation of a tail-gas scrubber, required to meet 1975 regulations, would further lower the total emissions to 15,000 metric tons per year.

Total Emissions. Estimated controlled and uncontrolled emissions (in millions of metric tons) for selected years are as follows:

Fiscal Year	Mode	Sulfur Oxides
1971	Without Further Control	1.16
1975	Without Further Control	1.16
	With Further Control	0.02
1979	Without Further Control	1.16
	With Further Control	0.02

Control Technology

The sulfur content of natural gas is related to the field from which the gas originates. Most of the sulfur present in natural gas is in the form of hydrogen sulfide. The hydrogen sulfide content of natural gas may vary from virtually nil to as high as 76 percent by volume. Natural gas which is transported and sold in the United States has a hydrogen sulfide content of less than 0.25 grains per 100 standard cubic feet of methane.

If the sulfur content of the gas is sufficiently high, a Claus unit may be installed to economically recover up to 94 percent of the input sulfur. Additional control will be required to meet the 1975 air quality regulations. A tail-gas scrubber must then be installed in conjunction with the Claus unit.

Claus Plants. These units produce elemental sulfur from the hydrogen sulfide in sour gas obtained principally from natural gas and petroleum refining. Several variations of the Claus process are available: the process choice is primarily a function of the H_2S concentration in the sour gas feed.

The unrecovered sulfur appears in the Claus plant tail-gas principally as hydrogen sulfide, elemental sulfur, and sulfur oxides. In the past, this tail-gas normally has been incinerated to convert the unrecovered sulfur compounds to sulfur oxides prior to release to the atmosphere.

Tail-Gas Scrubbers. In order to meet the 1975 air quality standards , it is necessary to use additional processing to reduce the quantity of sulfur in the Claus plant tail-gas. Three promising systems are considered here for the development of cost information.

The Shell Process is said to be capable of virtually complete sulfur removal. The process features a reduction stage, in which all sulfur compounds and elemental sulfur in the Claus off-gas are reduced to hydrogen sulfide. The reduction stage is followed by an absorption stage in which the hydrogen sulfide is selectively removed by amine scrubbing. After regeneration, recovered hydrogen sulfide is recycled to the Claus unit.

The Beavon Sulfur Removal Process is reportedly proven in a pilot-plant operation in California. The Claus plant tail-gas is mixed with hot combustion gas produced by burning fuel gas with air. This mixture is passed through a catalytic reactor to convert all the sulfur to hydrogen sulfide. Water is then condensed before this gas is passed through a Stretford section, where the hydrogen sulfide is removed and converted to elemental sulfur.

The Cleanair Sulfur Process has been installed in a Claus plant in Canada. This process employs a Stretford Process section. Claus-Cleanair units are available as a tandem unit; alternatively, a Cleanair Unit can be added to an existing Claus plant.

Control Costs

Control costs have been computed for eight model plant sizes for plants with Claus units and for plants without Claus units. Selected model plant control costs are presented in Table IV-2.

A summary of the estimated direct control costs for natural gas processing plants in meeting air quality standards on sulfur oxide emissions in the period from FY 1971 through FY 1979 is as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	90	79	104.6
Annual Costs			
Capital Charges	10.6	9.3	12.3
Operating and Maintenance	16.7	14.6	18.6
Total Annual Costs	27.3	23.9	30.9
Cash Requirements	216.9	199.2	235.2
New Facilities	(not applicable)		

TABLE IV-2. COSTS OF CONTROL FOR SELECTED MODEL NATURAL GAS PROCESSING PLANTS

Model Size, metric tons sulfur per day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost,[(a)] $/unit		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
				Claus Plant Plus Tail-Gas Scrubber					
5	454	314	608	125	84	165	108		
60	1718	1258	2244	652	429	734	29		
100	2242	1639	2981	884	612	1182	24		
750	6488	4589	8674	3586	2235	4946	13		
				Tail-Gas Scrubber on Existing Claus Plant					
5	253	168	334	46	28	61	25		
60	869	628	1127	220	159	297	10		
100	1157	810	1534	316	207	436	9		
750	3149	2300	4142	1356	898	2889	5		

(a) Unit cost = $/annual metric ton sulfur capacity.

Petroleum Industry

Introduction and Summary

Nature of the Products and Processes. The three major sources of air pollution in the petroleum industry covered in this study are: (1) regeneration of catalysts used in catalytic cracking, (2) burning of off-gases from various refinery process operation in order to recover the fuel values, and (3) handling and storage of volatile petroleum products and crude oils. A consolidated view of the type and extent of the emissions from refining and related operations, and the costs that may be involved in reducing them to levels meeting state and Federal regulations, is presented below.

In catalytic cracking, carbon deposited on the catalyst must be removed continuously in order to maintain catalyst activity. In burning the carbon from the catalyst, substantial quantities of particulates, carbon monoxide, unburned hydrocarbons, and any sulfur contained in the carbon are carried off in the flue gases. Particulate emissions may be controlled by use of electrostatic precipitators. The carbon monoxide and hydrocarbons can be burned to less noxious gases either with or without the recovery of energy in the form of steam. Reduction in sulfur oxide emissions will require the use either of low-sulfur charging stocks or treatment of flue gas.

Refinery off-gases (fuel gases) from crude-oil distillation and various subsequent high-temperature processing operations contain about one-half of the sulfur present in the crude oil in the form of hydrogen sulfide. If present in sufficient quantities to cause corrosion, catalyst poisoning, or odor emissions problems, the hydrogen sulfide is separated from the off-gases by absorption in an amine solution (or by an equivalent treatment) and recovered as hydrogen sulfide which is either burned in a flare which emits sulfur oxides to the atmosphere, or is converted to sulfur in a Claus plant (or the equivalent). Proposed new Federal standards on sulfur oxide emissions would require installation of amine treatment facilities, Claus plants, and tail-gas treatment systems on virtually all U.S. refining capacity.

The most significant contribution to total hydrocarbon losses in the petroleum industry are associated with the necessary use of vast storage facilities. The National Petroleum Council has shown that the entire industry has found it necessary to maintain a total storage capacity of at least two barrels for each barrel of actual inventory. This surplus storage is the minimum amount of storage to maintain flexibility in refinery operation and to provide for seasonal variations in demand.

Crude oil is supplied to refineries through a transportation system which includes tank farms, bulk terminals, and other storage points outside the refinery. Many refineries serve as the first link in the system for marketing and distribution of petroleum products. The bulk of all refinery products are transported by pipeline to large storage facilities such as bulk terminals and bulk stations.

Hydrocarbon emissions from storage vessels depend on three basic mechanisms: breathing loss, working loss, and standing storage loss. Breathing and working losses are associated with fixed-roof tanks, while standing storage losses are associated with floating-roof tanks. The magnitude of hydrocarbon emissions from storage vessels depends on many factors including the physical properties of the material being stored, climatic and meteorological conditions, and the size, type, color, age, and physical condition of the tank.

New Federal standards on hydrocarbon emissions will require installation of floating-roof tanks (or the equivalent) for the storage of crude oil and petroleum products which exhibit vapor pressures in the range 78 to 570 millimeters mercury.

Emissions and Control Costs. Emissions from catalytic cracking, fuel-gas burning at refineries, and storage of crude oil and volatile petroleum products in FY 1971 (without further controls) and in FY 1979 (with further controls) are estimated in thousands of metric tons per year.

Fiscal Year	Mode	Source	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
1971	Without Further Control	Catalytic Cracking	130	260	7,400	120	36
		Fuel Gas Burning		3,400			94
		Storage				910	
		Total	130	3,660	7,400	1,030	130
1979	With Further Control	Catalytic Cracking	36		10	Neg	55
		Fuel Gas Burning		68			105
		Storage				275	
		Total	36	68	10	275	160

Total industry control costs for the period FY 1971 through FY 1979 are estimated to require an investment of about $850 million. Annualized costs for the industry are estimated at $130 million, allowing no credit for additional steam recovery through installations of CO- boilers in catalytic cracking units. On the basis of an assumed credit of $0.82 per million Btu for this steam, annualized costs might be reduced by a maximum estimated $109 million. At the present time, it is judged that only a small but indeterminate fraction of this by-product steam could be utilized effectively.

Industry Structure

Characteristics of the Firms. The petroleum industry can logically be divided into five major divisions: exploration, production, refining, transportation, and marketing. Exploration is concerned with the search for new crude-oil supplies. Production includes the operations involved in drilling oil fields, determining best production methods, removing oil from the ground, and pretreatment at the well site. The extent of pretreatment depends on the type of crude oil, and usually involves removal of gas and brine. Refining is limited to the operations necessary to convert the crude oil into salable products, namely: gasoline, kerosene, distillate fuel oils, residual fuel oils, lubricants, asphalt, and a host of specialty products. Petroleum-derived chemicals such as ethylene, propylene, toluene, and benzene, also serve as vital feedstocks to the petrochemical industry. Transportation involves movement of crude oil to the refinery and refined products to market areas. Marketing involves the distribution and sale of the finished petroleum products.

Integration and diversification prevail within the industry. Most of the firms involved in refining also produce crude oil or market the refined products, or do both. In fact, the refinery portion of the business is generally not the major activity. Refinery investment is only some 13 percent of the total gross investment in the domestic oil industry. All large- and medium-sized firms have diversified into chemical production. A few companies have entered into other nonrelated areas of business.

Current Capacity and Growth Projections. As of January 1, 1973, the 247 refinery operations in the United States were capable of processing 13.4 million barrels of crude oil daily. A distribution of these refineries by size and percent of total capacity is

Average Refinery Capacity, 1000 barrels per calendar day	Number of Refineries	Total Capacity, 1000 barrels per calendar day	Percent of Total Industry Capacity	Average Capacity, 1000 barrels per calendar day
0 to 5	43	117	0.87	2
5 to 10	35	221	1.65	6
10 to 15	17	194	1.45	11
15 to 25	26	484	3.61	18
25 to 50	46	1,644	12.26	35
50 to 75	19	1,136	8.47	59
75 to 100	20	1,756	13.09	87
100 to 200	26	3,449	25.72	132
200 and up	15	4,410	32.88	294
Totals	247	13,414	100.00	

During the period of 1967 to 1973, total crude processing capability increased by 2.3 million barrels per day, despite a drop in the number of refineries from 261 to 247, indicating a gradual trend toward larger installations. Over 80 percent of the total refining capacity is dominated by 16 major firms, each of which controls crude processing capacity in excess of 200,000 barrels per day. A breakdown of refinery capacity and number of plants operated by these firms is as shown on the following page.

In 1972, petroleum products (crude oil and natural-gas liquids) supplied about 45 percent of the total energy requirements of the United States. By way of comparison, natural gas supplied 32 percent, coal 17 percent, hydropower 4 percent, and nuclear energy less than 1 percent of the energy budget. A recent study by the National Petroleum Council estimated a growth in demand for petroleum products of 4.2 percent per year between 1970 and 1980. To maintain the same relative relationship of U.S. crude oil refining capacity to domestic demand would require a growth in capacity from about 12.4 million barrels per day in mid-1970 to 18 million barrels per day by mid-1980. The uncertainties regarding import regulations and availability of crude oil and refined products and difficulties in obtaining suitable sites for new grass-roots refineries, have resulted in essentially zero growth during the past 2 years. While plans to expand present refining operations and to build new plants have been announced, it will take a minimum of 2 to 3 years to construct these new units and to get them into full production. In the meantime, construction of new and enlarged refineries in the West Indies, the Caribbean, and eastern Canada will absorb some of the anticipated increased demand for petroleum products over the next few years.

Company	Number of Refineries	Crude Capacity, 1000 barrels per calendar day	Cat Cracking Feed, barrels per stream day	Percent of Crude Capacity
Exxon	5	1,156	488	8.6
Texaco	12	1,110	443	8.3
Shell	8	1,083	368	8.1
Amoco	10	1,022	343	7.6
Standard (Calif.)	13	960	208	7.2
Mobil	9	930	335	7.0
Gulf	8	845	319	6.3
ARCO	6	773	210	5.8
Sun	5	462	202	3.5
Union	4	446	129	3.3
Sohio/BP	5	406	145	3.0
Phillips	6	404	174	3.0
Ashland	7	351	119	2.6
Conoco	7	328	103	2.5
Cities Service	1	240	113	1.8
Marathon	3	223	74	1.7
Subtotals	109	10,737	3,773	80.3
Remaining 115 Firms	138	2,646	740	19.7
Totals	247	13,385	4,513	100

In the following paragraphs, current capacity and growth projections for catalytic cracking, fuel-gas burning, and petroleum and petroleum-product storage are presented.

Of the 247 petroleum refineries in the United States in 1973, 146 operate catalytic cracking units. Total processing capacity is about 4 million barrels per day of fresh feed, with an additional recycle stream of about 1 million barrels per day.

Additions to catalytic cracking capacity will depend upon the demand for gasoline. This capacity is anticipated to increase from 4.5 million barrels per day of fresh feed in 1973 to about 5.85 million barrels per day by mid-1979, assuming a continuation of existing refining practices. Improvements in catalytic-cracking technology are expected to reduce recycle operations from 1 million barrels per day in 1973 to less than one-half million barrels per day by FY 1979.

More than 80 percent of the crude-oil processing and catalytic cracking operations are presently conducted in refineries of at least 50,000 barrels of crude oil capacity per day. The trend to larger refining operations is expected to continue. Over the next 5 years, it is believed that less than 100,000 barrels per day of new catalytic cracking capacity will be installed in refineries of approximately 10,000 barrels per day, compared with about 1.2 million barrels of new catalytic cracking capacity installed in refineries of approximately 50,000 barrels per day.

It is estimated that the 247 domestic refineries produce about 2.3 billion scfd of refinery fuel gases. By 1979, new refinery capacity is expected to produce an additional 0.62 billion scfd of gas. Present Claus plant capacity for recovering sulfur from refinery gases is about 6,500 metric tons sulfur per day. The expected increased sulfur content of crude oils, plus growth in refining capacity, will require a growth in Claus plant capacity and tail-gas scrubbing systems to about 18,700 metric tons per day by FY 1979.

Crude-oil storage capacity is estimated at about 400 million barrels in FY 1971, increasing to 425 million barrels in FY 1979. Gasoline storage capacity is estimated at about 350 million barrels in FY 1979. Jet fuel (naphtha) storage capacity will increase from about 9.2 million barrels in FY 1971 to 9.8 million barrels in FY 1979. Less volatile products such as distillate fuel oils, kerosene, gas oils, residual fuel oils, and heavy crude oils have not been included; these products can be stored in fixed-roof tanks without excessive evaporation, and they are not included in the New Source Performance Standards for petroleum-products storage.

Emissions Sources and Pollutants

Refinery emissions and typical sources are

Emissions	Sources
Sulfur Oxides	Boilers
	Process Heaters
	Cat Cracker/Regenerators
	Treating Units
	Flares
	Decoking Operations
Nitrogen Oxides	Boilers
	Process Heaters
	Catalyst Regenerators
	Flares
	Compressor Engines
Particulates	Catalyst Regenerators
	Boilers
	Process Heaters
	Decoking Operations
	Incinerators
Carbon Monoxide	Catalyst Regenerators
	Decoking Operations
	Compressor Engines
	Incinerators
Hydrocarbons	Loading Facilities
	Turnarounds
	Sampling
	Storage Tanks
	Waste Water Separators
	Blowdown Systems
	Catalyst Regenerators
	Pumps
	Valves
	Blind Changing
	Cooling Towers
	Vacuum Jets
	Barometric Condenser
	Air-blowing
	Process Heaters
	Boiler
	Compressor Engines

Emissions from catalytic-cracking operations, fuel-gas burning, and petroleum storage comprise the vast bulk of air emissions requiring additional controls to enable the petroleum industry to meet state and Federal regulations. Total estimated emissions from these three sources are (in thousands of metric tons per year):

Fiscal Year	Mode	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
1971	Without Further Control	130	3,660	7,400	1,030	130
1975	Without Further Control	160	4,700	8,800	1,075	135
	With Further Control	27	45	neg	850	135
1979	Without Further Control	210	9,740	11,300	1,180	160
	With Further Control	36	68	10	275	160

In the following paragraphs, emission sources and estimates for catalytic cracking, fuel-gas burning, and petroleum crude and product storage are presented.

The carbon deposited on the catalyst used in catalytic cracking must be removed continuously to maintain activity of the catalyst in converting charging stocks to high-octane gasoline and other desired products. In burning the carbon from the catalyst with air, substantial quantities of particulates, carbon monoxide, unburned hydrocarbons, and any sulfur contained in the carbon are generated. Some nitrogen oxides are formed at the combustion temperatures normally used in catalyst-regeneration operations. Emissions of sulfur oxides depend upon the sulfur content of the feedstock processed in catalytic-cracking operations; approximately 5 percent of the feed sulfur is retained by the carbon on the catalyst pellets. This retained sulfur subsequently is burned off during regeneration. The use of higher cracking temperatures and newer catalysts--which reduces the amount of carbon deposition on the catalyst--tends to reduce sulfur oxides emissions during catalyst regeneration. So also would the use of desulfurized or low-sulfur feedstocks.

The best achievable but necessarily rough estimates of emissions from cracking-catalyst-regeneration operations are as follows (in thousands of metric tons per year).

Fiscal Year	Mode	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
1971	Without Further Control	130	260	7,400	120	36
1975	Without Further Control	160	310	8,800	135	45
	With Further Control	27	--	neg	neg	45
1979	Without Further Control	210	400	11,300	180	55
	With Further Control	36	--	10	neg	55

Emissions of sulfur oxides from fuel-gas burning are a function of the sulfur content of the crude oil being processed, the complexity of the refinery, and its energy balance. Sulfur enters the refinery in the crude oil, in any purchased fuel oil or gas, and in sulfuric acid purchased for use in various processes. A large part of this sulfur routinely leaves the refinery in the various products, as spent sulfuric acid shipped out for regeneration, as sulfides or sulfates in the liquid wastes, or as by-products of sulfur-recovery plants. The remainder could be emitted to the atmosphere mainly as sulfur dioxide, although some higher sulfur oxides and hydrogen sulfide may be released.

Proposed Federal standards for new refineries or additions to existing refineries would limit sulfur oxide emissions from heaters, boilers, and flare stacks by specifying a limit on the hydrogen sulfide content of the fuel burned, unless the combustion gases are treated in a manner equally effective in preventing the release of sulfur oxides to the atmosphere.

Accurate estimation of refinery sulfur emissions based on average values is extremely difficult if not impossible. Each refinery should be considered separately. Such a massive effort was beyond the scope of the present program; therefore, very rough material balances were based on model refineries and average crude oil sulfur contents. Estimated sulfur emissions were based on the assumptions that the average sulfur content of the crude oil processed in U.S. refineries in 1975 is 0.9 percent, and that present sulfur-recovery capacity exists to recover slightly more than one-half of this sulfur. It was further assumed that all refining capacity installed in the U.S. between 1975 and 1979 will process a mixture of imported Middle East crude with an average sulfur content of 2 percent.

The estimate of sulfur oxides emissions from fuel-gas burning in refinery operations for FY 1971 was based on the assumption of full utilization of existing sulfur-recovery facilities. The following estimates of sulfur oxides emissions (in thousands of metric tons per year are based on the assumption of a present recovery of 2.2 million metric tons of sulfur in FY 1971:

Fiscal Year	Mode	Sulfur Oxides	Nitrogen Oxides
1971	Without Further Control	3,400	94
1975	Without Further Control	4,400	90
	With Further Control	45	90
1979	Without Further Control	9,340	105
	With Further Control	68	105

Hydrocarbon emissions from storage vessels depend on three basic mechanisms: breathing loss, working loss, and standing-storage loss. Breathing and working losses are associated with fixed-roof tanks; standing-storage losses are associated with floating-roof tanks.

The magnitude of hydrocarbon emissions from storage vessels depends on many factors, including the physical properties of the material being stored, climatic and meteorological conditions, and the size, type, color, age, and condition of the tank. Emissions from tanks with known physical characteristics can be calculated with reasonable accuracy. For the purposes of this study, average factors which cover a wide variety of tank sizes and conditions have been used. Emissions without controls are estimated for FY 1971 at 1 million barrels, increasing to 1.1 million barrels in FY 1979.

Estimated hydrocarbon emissions (in thousands of metric tons per year) are as follows:

Fiscal Year	Mode	Hydrocarbons
1971	Without Further Control	910
1975	Without Further Control	940
	With Further Control	850
1979	Without Further Control	1,000
	With Further Control	275

Control Technology

Catalytic Cracking. Equipment to control emissions of carbon monoxide, hydrocarbons, and particulate matter is commercially available. Particulate emissions may be controlled by the use of electrostatic precipitators. Carbon monoxide and hydrocarbons can be burned to less noxious gases with or without heat recovery in the form of steam. Sulfur oxide emissions can be reduced to acceptable levels through use either of low-sulfur charging stocks or treatment of the flue gas after burning. In the past, process economics have precluded installation of waste-heat (carbon monoxide) boilers on about 40 percent of the fluid catalytic-cracking capacity. To meet new state and Federal regulations, more CO-boilers will be required on existing facilities to save waste energy. Improved designs on new refinery facilities will minimize the total refinery energy requirement.

Fuel-Gas Burning. Currently, amine scrubbing units are used to remove hydrogen sulfide from refinery gases. New processes that employ other scrubbing media also are being applied to refinery process gases.

In the usual amine scrubbing practice, hydrogen sulfide is thermally stripped from the amine scrubbing liquor, then either burned to sulfur dioxide which is emitted to the atmosphere through a flare, or sent to a sulfur recovery plant (usually a Claus plant) for conversion to sulfur.

The control system consists of amine treatment facilities capable of meeting the proposed new source performance standards (or their equivalent) followed by a sulfur recovery (Claus) plant. In anticipation of more restrictive future regulations on emissions of sulfur oxides, further treatment of the tail gas leaving the Claus plant is included. At least seven tail-gas treatment systems are being offered commercially. With the exception of those in Los Angeles County and the San Francisco Bay area, few refineries have installed tail-gas processing units. Therefore, four model plant categories were set up to account for the different situations encountered with existing equipment and the different requirements imposed by the control technology:

- Type 1: Existing refineries that now flare stripped hydrogen sulfide directly to atmosphere will need to expand and/or modify existing amine scrubbing capacity, and install new sulfur recovery (Claus) plant capacity with tail-gas processing facilities.

- Type 2: Existing refineries that now recover sulfur but which do not have adequate capacity to meet emissions standards will need to expand and/or modify existing amine scrubbing capacity and install new sulfur recovery (Claus) plant capacity with tail-gas processing facilities.

- Type 3: New grass-roots refineries that will be built complete with amine scrubbing units and sulfur-recovery (Claus) plant capacity with suitable tail-gas processing facilities in accord with required emissions standards.
- Type 4: Existing refineries that have adequate sulfur-recovery (Claus) plant capacity but which need to expand and/or modify existing amine scrubbing facilities, and add Claus plant tail-gas processing facilities.

Petroleum and Petroleum Product Storage. New Source Performance Standards for petroleum storage vessels are couched in terms of specific control equipment rather than in terms of allowable hydrocarbon emissions. Petroleum products having a true vapor pressure (at actual storage conditions) between 78 and 570 millimeters mercury must be stored in tanks equipped with a floating roof, or the equivalent. This standard would require the conversion of existing fixed-roof tanks to floating-roof tanks; all new storage facilities for petroleum products in this vapor-pressure range would require floating-roof tanks. For petroleum products having a vapor pressure greater than 570 millimeter mercury, normal industry practice generally has been to employ vapor-recovery systems in line with the New Source Performance Standards and in consideration of the value of the stored product.

Control Costs

A summary of the total direct control costs for the period FY 1971 through FY 1979 to reduce emissions from catalytic cracking, fuel-gas burning, and petroleum-storage operations to the required levels is

	Expected Cost, $ millions			
	Fuel-Gas Burning	Catalytic Cracking(a)	Petroleum Storage	Total
Existing Facilities				
Investment	306	175	96	577
Annual Costs				
Capital Charges	40	25	11	76
Operating and Maintenance	50	28	-6	72
Total Annual Costs	90	53	5	148
Cash Requirements	771	387	116	1274
New Facilities				
Investment	170	100	3	273
Annual Costs				
Capital Charges	22	14	0.3	36.3
Operating and Maintenance	42	15	-0.6	56.4
Total Annual Costs	64	29	-0.3	92.7
Cash Requirements	348	176	2	526

(a) Assumes no steam credit for operation of CO-boilers; Steam credit at $0.82 per million BTU would reduce operating and maintenance costs and cash requirements by the following amounts:

	$ millions	
	Existing	New
Operation and Maintenance	$ 58	$50
Cash Requirements	325	152.

Investment costs are estimated at $476 million for control of fuel-gas burning, $275 million for catalytic-cracking operations, and $100 million for conversion to and/or installation of floating-roof storage tanks, for a total of $850 million. The ranges for the estimated control costs for the Petroleum Industry are presented in Table IV-3.

Annualized costs are estimated at $240 million, assuming no credit for steam produced in CO-boilers. On the other hand, a steam credit of $0.82 per million Btu would reduce these costs by $108 million. The actual value of the steam would depend on the economic feasibility of utilization of existing installation. The increasing cost of energy and growing scarcity of low-cost natural gas should improve the economics of increased steam use over time.

Cash requirements for the period FY 1971-1979 are estimated at $1.8 billion, assuming no steam credits; a steam credit of $0.82 per million Btu would reduce the cash requirement by almost $400 million.

The costs of controlling hydrocarbon emissions from loading and unloading of small tanks, tank trucks, and servicing of vehicles at terminals, bulk plants, and service stations are not covered in this study. The costs involved in controlling these hydrocarbon emissions may be well in excess of $1 billion, or considerably more than the cost of the primary industry controls. Other costs relevant to the petroleum industry have been addressed in other sections of this report. These include the use of lead-free and low-lead gasoline in Chapter III; Mobile Source Emission Control; oil desulfurization in Chapter V; Fossil Fuel Burning Sources; and control of sulfur in natural gas in the section on Natural Gas Processing Plants.

TABLE IV-3. COST OF CONTROL FOR PETROLEUM INDUSTRY

	Catalytic Cracking,[a] $ Millions			Fuel Gas Burning, $ Millions			Petroleum Storage $ Millions			Total Industry, $ Millions		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Existing Facilities												
Investment	175	145	206	306	259	364	96.3	86.8	103.9	577	491	674
Annual Costs												
Capital Charges	25.1	21.9	28.3	40.2	34.1	47.8	10.3	9.2	10.9	75.6	65.2	87.0
Operating and Maintenance	27.6	21.5	33.6	49.8	19.2	70.5	-5.7	-6.7	-4.6	71.7	34.0	99.5
Total Annual Costs	52.7	43.4	61.9	90.0	53.3	118.3	4.6	2.5	6.3	147.3	99.2	186.5
Cash Requirements	412	353	471	771	551	945	114	98.5	130	1297	1003	1546
New Facilities												
Investment	101	83.7	118	472	395	559	2.64	2.52	2.74	576	481	680
Annual Costs												
Capital Charges	14.0	11.6	16.4	22.3	18.2	26.1	0.28	0.27	0.29	59.3	30.1	42.8
Operating and Maintenance	15.2	11.7	18.7	42.2	30.0	54.3	-0.51	-0.59	-0.46	56.9	41.1	72.5
Total Annual Costs	29.2	23.5	35.1	64.5	48.2	80.4	-0.23	-0.32	-0.17			
Cash Requirements	177	153	202	348	284	403	1.80	1.55	2.04	527	439	607

(a) Assumes no steam credit for operation of CO-boilers; Steam credit at $0.82 per million Btu would reduce operating and maintenance costs and cash requirements as follows:

	$ millions	
	Existing	New
Operation and Maintenance	$ 58	$50
Cash Requirements	325	152.

CHEMICAL INDUSTRIES GROUP

Carbon Black

Introduction and Summary

Nature of the Product and Processes. Almost 94 percent of the carbon black production is used by the rubber industry, largely in the manufacture of tires. Other major consumers include inks, paints, plastics, and paper industries. Various grades and types of carbon black are produced to meet the varied end-use requirements.

The oil furnace process comprises almost 90 percent of present capacity, while most of the other production is by the thermal process. Production by the channel process is presently less than 1 percent of the total production.

In the furnace process, emissions of carbon black particulates are controlled through utilization of bag filters for the separation and collection of carbon black, and by utilization of bag filters or water scrubbers on the vent gas from driers, pneumatic conveyor systems, and vacuum clean-up systems. Spills that may occur through handling operations or equipment failure will result in periodic discharges of carbon black. Other major emissions are carbon monoxide, hydrocarbons, and hydrogen sulfide. Flares, either singly or in combination with waste-heat boilers, could be used to reduce the emissions of carbon monoxide, hydrocarbons, and hydrogen sulfide to low levels if required to meet air-quality standards; the sulfur dioxide content would increase due to the oxidation of the hydrogen sulfide.

In the thermal process, which involves cracking of natural gas to carbon and hydrogen, the sulfur contained in the natural gas would be the only emission other than carbon black emissions that may occur in handling operations.

The only means of controlling emissions in the channel process is through restriction of production. Only two channel plants were operating in 1972.

Emissions and Control Costs. Carbon monoxide emissions without controls are estimated to increase from 1.6 million metric tons in FY 1971 to 2.3 million metric tons in FY 1979. Installation of plume burners on existing plants and thermal incinerators plus waste-heat boilers on new plants would reduce these emissions to about 175,000 metric tons in FY 1979. Such installations would also reduce emissions of hydrocarbons and hydrogen sulfide, but would increase sulfur oxides emissions from 13,000 metric tons to 44,000 metric tons, based on present sulfur content of feed stock.

Control costs have not been estimated for the carbon black industry as emission standards have not been established. Preliminary studies on costs for plume burners and incinerators with waste-heat boilers have indicated that costs involved in the installation of such equipment might add 0.5 to 1.5 percent to the cost of carbon black, or about $1 million to $3 million annually at present production rates. Actual costs may be appreciably higher.

Industry Structure

Characteristics of the Industry. In 1972, eight producers of carbon black operated 34 carbon-black plants in nine states. Production of carbon black was 1.45 million metric tons or about 77 percent of the rated capacity. Almost 94 percent of the carbon black is used by the rubber industry, 70 percent of which is utilized in manufacturing tires. Other major consumers include the inks, paints, plastics, and paper industries.

Three processes for making carbon black in order of importance are

- Oil furnace process
- Thermal process
- Channel process.

The oil furnace process comprises almost 90 percent of present capacity. In this process technological methods that have been developed permit control of particulate emissions at better than 99 percent efficiency and meet air-pollution regulations when the equipment is operating properly. In present practice, natural gas is generally burned to furnish the required heat.

The thermal process involves cracking natural gas to carbon and hydrogen. In this process, the hydrogen, unrecovered carbon, and unconverted methane are recycled or used for fuel. Under optimum processing operations, the only emissions would be from the sulfur contained in the natural gas and the carbon black from various handling operations.

The channel process, under normal operations, allows large quantities of carbon black to escape to the atmosphere. The low efficiency of this process and the inability to control the production process to eliminate venting to the atmosphere led to the development of the furnace and thermal processes. Improvements in processing methods have enabled the manufacturers to produce virtually all grades of carbon black as satisfactory replacements to those produced by the channel process.

Seven major grades of furnace black plus thermal and channel blacks are produced. Within these major categories are a substantial number of variations in specifications for different uses. Individual producers are also constantly working to improve characteristics of their carbon blacks. Increasing prices and potential shortages of natural gas will reinforce the trend to oil furnance blacks as the major production method.

Current Capacity and Growth Projections. The capacity of carbon black plants has increased at an annual growth rate of almost 4.5 percent over the past decade, compared with a growth in production rate of 4.3 percent per year. A breakdown of estimated capacities by state showing new and replacement capacities from 1974 to 1979 is shown below:

	Capacity, 1972		New and Replacement Capacity, 1979	Total Capacity, 1979	
	Million kg/yr	Furnace, % of total U.S.	Million kg/yr	Million kg/yr	Furnace, % of total U.S.
Ala.	23	1.38	11	34	1.59
Ark.	44	2.64	23	45	2.11
Calif.	79	4.75	23	91	4.26
Kan.	26	1.56	23	45	2.11
La.	661(a)	30.19	136	750(a)	26.59
Ohio	73	4.39	64	136	6.37
Okla.	39	2.34	34	57	2.67
Texas	804(b)	46.00	255	1000(c)	45.74
W. Va.	114	6.86	68	182	8.52
Total U.S.	1863		637	2340	
Furnace Capacity, U.S.	1663			2136	

(a) Includes an estimated 159 million kg/yr thermal process capacity in 1972 and 182 million kg/yr in 1979.

(b) Includes 16 million kg/yr of thermal process capacity and 24 million kg/yr of channel process capacity.

(c) Includes an estimated 23 million kg/yr of thermal process capacity. No channel process capacity.

Estimated 1971 capacity is about 1,800 million kilograms. On the basis of an estimated increase in demand of 4.5 percent per year, production in 1979 would be about 2,000 million kilograms, or an increase of 36 percent. Present capacity is greater than that required to meet present demand, but increased prices and the scarcity of natural gas will force a continuing shift from the thermal process to increased dependence on the oil furnance process to meet requirements for carbon black. Assuming (1) growth in demand will be met from new and/or expanded capacity and, (2) an annual production rate of 85 percent of total capacity will be attained, a minimum increase in capacity of almost 0.45 million metric tons per year will be required by 1979. In addition, some replacement and/or modernization and expansion of present facilities will take place. Assuming a 10 percent replacement of existing capacity would indicate the need for an additional 0.18 million metric tons per year of new capacity. While the trend has been to expand production capabilities close to major markets, Texas and Louisiana are expected to continue as the major producing states.

Only two channel black plants remained in operation in 1972, during which year, production declined to 10 million kilograms compared with 21 million kilograms in 1971. No production by this process is projected for 1979.

Emission Sources and Pollutants

Emissions from the furnace processes comprise carbon-black particulates (from the processing, drying, and handling operations), and hydrocarbons, carbon monoxide, sulfur oxides, and nitrogen oxides as combustion products from the processing operations. These emissions vary depending on the process design, types of carbon black being produced, emission-control equipment presently installed, and raw materials used.

Emissions from thermal-process plants would consist of carbon-black particulates escaping during pulverizing, pelletizing, storage, and loading operations, plus combustion products from contaminants in the excess hydrogen used to fire boilers for plant steam and electric power. Emissions from these sources are believed to be well within air-quality standards under normal operations.

Emissions from the two operating channel-black plants have not been determined. Cabot has stated that when production is limited to high-color blacks, one channel-black plant is able to comply fully with the Texas Clean Air regulations.

Emission standards have not been established for carbon black plants. When required, order-of-magnitude reductions in emissions could be achieved through installation of plume burners on existing furnace plants. Sulfur oxides emissions would be increased (replacing hydrogen sulfide emissions). There would be some increase in nitrogen oxides emissions.

Estimated emissions (in thousands of metric tons) from furnace black plants are as follows:

Fiscal Year	Mode	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
1971	Without further control	3.5	9.1	1,630	69	3.0
1975	Without further control	4.1	10.9	1,900	79	3.4
	With further control	-	-	-	-	-
1979	Without further control	4.9	12.7	2,270	93	4.2
	With further control	2.8	34.5	175	6.4	5.5

The emissions without further control shown for 1979 assume (1) continuation of present practices, (2) installation of plume burners on existing plants with thermal incinerators and waste-heat boilers installed on new and replacement facilities, and (3) no increase in sulfur content of charge stock. Note that estimated controlled emission of sulfur and nitrogen oxides increases in FY 1979 as a result of the application of controls for emissions of hydrocarbons, carbon monoxide, and particulates.

Control Technology

The history of the carbon-black industry is one of developing technologies (1) to control the emissions of carbon black, (2) to increase the yield of carbon black, and (3) to improve the qualities of the various grades and types of carbon black in meeting end-use requirements. In recent years, the development of high-temperature bag filters, leading to substantial improvements in separation and collection equipment for the furnace process, permitted a recovery efficiency of particulates of better than 99 percent. Installation of bag filters or water scrubbers on the vet gas from the driers, pneumatic converyor systems, vacuum clean-up systems, and additional concrete surfacing in plant areas have further minimized the escape of the finely divided carbon black into the atmosphere. Spillage and leaks, however, will result in periodic discharges of carbon black and will require continuing attention and stress on good housekeeping practices and maintenance of equipment in top operating condition.

Control Cost

In the past, the low cost of energy made recovery of heat from the low-Btu gas containing carbon monoxide economically unattractive. Where hydrogen sulfide is present in objectionable quantities in the off-gas plume, flares have been used to remove the odor by converting the hydrogen sulfide to sulfur dioxide. Most of the carbon monoxide would be burned. Increasing concern over carbon monoxide pollution of the atmosphere, coupled with higher costs for steam and electric power, indicate the possible need and desirability of installing flares. These could be installed either singly or in combination with waste heat boilers on existing plants, and on thermal incinerators with steam generation on new plants. Preliminary estimates based on unpublished data indicate that the costs of installing such equipment might add from 0.5 to 1.5 percent to the cost of the carbon black, or about $1 million to $3 million annually.

The Chlor-Alkali Industry

Introduction and Summary

Nature of Project and Process. High-purity caustic soda and chlorine are coproducts in the electrolytic process which uses flowing mercury metal as a moving cathode. The caustic soda product finds major markets in those chemical manufacturing operations where high-purity and freedom from sodium chloride and metal impurities are in demand. Of the two basic processes for producing chlorine, only the one employing the mercury cell can cause mercury emissions.

Emissions and Control Costs. Mercury emissions occur from the hydrogen by-product stream, the cell-ventilation gas, and from the cell-room ventilation air. In order to meet the new EPA hazardous emission regulations for mercury emissions, the users of mercury cells will be required to reduce emissions by approximately 95 percent from uncontrolled plant emissions. Mercury emissions are estimated to be 490 metric tons for FY 1971 without controls. With required controls in FY 1979, mercury emissions are estimated to be 24 metric tons.

Investment costs for the control of mercury emissions in the period FY 1971 to FY 1979 are estimated at $16.7 million. Annual costs are expected to be $6.5 million.

Industry Structure

Characteristics. Chlorine is produced almost entirely by the electrolysis of fused chlorides or aqueous solutions of alkali-metal chlorides. Chlorine is produced at the anode, while hydrogen and potassium hydroxide or sodium hydroxide derive from processes taking place at the cathode. Anode and cathode products must be separated, such as in a cell which employs liquid mercury metal as an intermediate cathode.

The use of the mercury cell in the United States has grown from 5 percent of the total installed chlorine capacity in 1946, toward a maximum of 28 percent of the installed U.S. chlorine capacity through 1968.

Current Capacity and Growth Projections. Current capacity is estimated at 6,970 metric tons chlorine per day for the 30 plants in operation in 1971. The size distribution of these plants is as follows:

Capacity Range (Chlorine Production) Tons/Day	Metric Tons/Day	Number of Plants	Percent of Total Capacity
0 - 100	0 - 90.7	5	3.5
101 - 200	90.8 - 181	9	17.5
201 - 300	182 - 272	8	27.2
301 - 500	273 - 454	5	25.9
501 - 750	455 - 580	3	25.9
Total		30	100.0

One new plant is scheduled for start-up in the first quarter of 1974; no other new mercury-cell plants are projected through 1979. After the new plant start-up, industry chlorine capacity is estimated to be 7,160 metric tons per day.

Emission Sources and Pollutants

The major sources of direct emissions of mercury to the atmosphere are:

- Hydrogen by-product stream
- End-box ventilation system
- Cell-room ventilation air.

The minimum known treatment of the by-product hydrogen gas leaving the decomposer consists of cooling the stream to 110 F followed by partial removal of the resulting mercury mist. For hydrogen saturated with mercury vapor at this temperature, the daily vapor loss is estimated to be 3.4 kg of mercury vapor per 100 metric tons of chlorine produced. The entrainment of condensed mercury in the hydrogen stream will result in additional emissions. The estimated uncontrolled emission of mercury vapor and mercury vapor and mercury mist, after minimum treatment has occurred, is estimated to be up to 25 kg per 100 metric tons of chlorine produced.

Mercury vapor and mercury compounds are collected from the end-boxes, the mercury pumps, and the end-box ventilation system. Preliminary results of source testing by EPA indicate that the mercury emissions from an untreated or inadequately treated end-box ventilation system range from 1 to 8 kg per 100 metric tons of chlorine produced.

In addition to cooling the cell room, the cell-room ventilation system provides a means of reducing the cell-room mercury-vapor concentration to within the recommended Threshhold Limit Value (TLV) for human exposure to mercury vapor. On the basis of data obtained from operating plants, it has been estimated that mercury emissions from the cell-room ventilation system vary from 0.2 to 2.5 kg per day per 100 metric tons of daily chlorine capacity, assuming a concentration equal to the TLV of 50 micrograms per cubic meter of ventilation air.

The Environmental Protection Agency has estimated that uncontrolled emissions from the production of chlorine in mercury cells averages approximately 20 kg of mercury per 100 metric tons of chlorine produced. On this basis, the estimated average annual mercury emissions for the Chlor-Alkali Industry are:

Fiscal Year	Mode	Mercury, metric tons
1971	Without further control	490
1975	Without further control	490
	With further control	24
1979	Without further control	490
	With further control	24

Control Technology

The cost estimates presented in this report are based upon the consideration and selection of the available control techniques in such a way as to insure compliance with the National Emission Standards for Hazardous Air Pollutants promulgated by EPA. This standard requires that the maximum daily emission of mercury from all sources be not greater than 2,300 grams from any single site.

Control techniques applicable to the hydrogen gas stream include: cooling, condensation, and demisting; depleted brine scrubbing; hypochlorite scrubbing; adsorption on molecular sieve; and adsorption on treated activated carbon. The adsorption of mercury vapor on treated activated carbon is a commercially available alternative; it was not applied in these estimates because regeneration and/or disposal of the spent carbon may pose emissions problems, and because the cost is roughly comparable to that for molecular-sieve adsorption.

With appropriate modification, the control techniques applicable to the end-box ventilation stream include cooling, condensing, and demisting; depleted brine scrubbing; and hypochlorite scrubbing. It is judged that the molecular-sieve adsorption system will become applicable in the near future to the end-box ventilation-gas stream. This control technique therefore has been applied to the estimations of costs for controlling mercury losses in the end-box ventilation stream in those situations where the application of no other control technique will permit compliance with the hazardous emission standard.

Mercury vapor from the cell-room ventilation air can be minimized by strict adherence to recommended good housekeeping and operating procedures. No other control technique is commercially tested at this time. The actual cost of instituting and promoting exceptionally good housekeeping and operating procedures cannot be assessed directly.

All mercury emissions could be eliminated by the conversion of mercury-cell plants to the use of diaphragm cells plus a special caustic soda purification system. Such conversion is judged to be an unacceptable alternative in terms of the very high estimated cost.

Control Cost

Because the hazardous emissions standard for mercury limits the maximum daily emission to 2,300 grams per plant, regardless of plant size, the cost computation was performed on a plant-by-plant basis. For each plant, specific control techniques were chosen to permit compliance with this emissions standard. Each plant therefore is its own mode. Table IV-4 presents estimated model plant control costs for selected plant sizes.

The estimated mercury emissions control costs for the chlor-alkali industry for the period FY 1971 through FY 1979 are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	16.2	14.8	17.8
Annual Costs			
Capital Charges	3.23	3.02	3.43
Operating and Maintenance	3.02	2.87	3.16
Total Annual Costs	6.25	5.89	6.59
Cash Requirements	39.2	37.2	41.4
New Facilities			
Investment	0.50	0.38	0.62
Annual Costs			
Capital Charges	0.10	0.07	0.13
Operating and Maintenance	0.09	0.07	0.11
Total Annual Costs	0.19	0.14	0.24
Cash Requirements	1.24	1.02	1.49

TABLE IV-4. COSTS OF CONTROL FOR SELECTED MODEL PLANTS IN THE CHLOR-ALKALI INDUSTRY (MERCURY CELLS)

Chlorine Capacity, metric tons per day	Investment, $1,000			Annualized Cost, $1,000			Unit Annual Cost*		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
68	221	172	261	74	61	86	1.09	0.90	1.26
135	363	244	522	147	108	193	1.09	0.80	1.43
320	846	724	986	309	261	361	0.97	0.82	1.13
410	975	846	1124	354	302	413	0.86	0.74	1.01
625	1270	1080	1490	444	372	522	0.71	0.60	0.84
680	1310	1100	1520	474	390	563	0.70	0.57	0.83

(a) $ per daily metric ton of chlorine capacity.

Nitric Acid

Introduction and Summary

Nature of Product and Process. Nitric acid is used in the manufacture of ammonium nitrate and in numerous other chemical processes. Ammonium nitrate, which is used as both a fertilizer and in explosives, accounts for about 80 percent of the nitric acid consumption. Nitric acid is produced by oxidation of ammonia followed by adsorption of the reaction products in dilute acid solution. Nitrogen oxides, the primary pollutants of concern in the production of nitric acid, are emitted in the tail gas from the absorption tower. Numerous variations on the basic nitric acid production process affect both the emissions and the difficulty of control. Two of the more important variables are the amount of excess oxygen present in the absorption tower and the pressure under which the absorption tower operates.

Most nitric acid plants in the United States are designed to manufacture acid with a concentration of 55 to 65 percent, which may then be subsequently dehydrated to produce 99 percent acid.

Many plants practice partial pollution abatement (decolorization) in accordance with local regulatory agencies. Under this practice, the highly visible reddish-brown nitrogen dioxide is reduced then to colorless monoxide. Although visible emissions are reduced, the practice does nothing to prevent emission of nitrogen oxides to the atmosphere. The following presents the emissions and costs attributable to the control of these nitrogen oxide emissions.

Emissions and Control Costs. Emissions of nitrogen oxides from the nitric acid industry in FY 1971 are estimated to be about 120,000 metric tons per year. In FY 1979, controlled emissions are estimated to be about 19,000 metric tons.

The required investment costs for the period from FY 1971 to FY 1979 are expected to be $35 million, most of which will be expended after July, 1974. The annualized cost expenditure is estimated at $13 million.

Industry Structure

Characteristics of the Firms. Nearly all nitric acid production in the United States is for captive consumption. In 1971, of the 6.7 million tons produced, less than 5 percent was sold in the merchant market. Production estimates for FY 1975 and 1979 are 6.9 million and 7.2 million metric tons, respectively.

At the beginning of 1973, there were 77 privately owned and operated nitric acid plants in the United States. In 1971, only 72 establishments reported to the Bureau of Census. It is believed that some captive producers did not report production. In addition to the privately owned facilities, 7 nitric acid plants are owned by the United States Government and operated by various contractor companies. These Government-owned nitric acid plants have not been included in cost estimates as part of the nitric acid industry.but instead are included in the Government Programs chapter.

Growth Projections. To meet industry growth, it is projected that two new facilities each with capacities of 910 metric tons per day and three new plants each with capacities of 318 metric tons per day will be required by FY 1979.

Emission Sources and Pollutants

Emissions from nitric acid plants consist of the oxides of nitrogen in concentrations of about 3000 ppm nitrogen dioxide and nitric oxide, and minute amounts of nitric acid mist. Nitrogen dioxide accounts for the reddish-brown color of unabated emissions from these plants. The major source of the emissions is the tail gas from the acid absorption tower. Emissions from nitric acid plants are typically of the order of 22 kg nitrogen oxides per metric ton of 100 percent acid produced.

Estimated controlled and uncontrolled emissions (in thousands of metric tons) of nitrogen oxides for selected years are as follows:

Fiscal Year	Mode	Nitrogen Oxides
1971	Without further control	120
1975	Without further control	106
	With further control	19
1979	Without further control	170
	With further control	19

Control Technology

Four control technologies are available to reduce the nitrogen oxide emissions to 1.5 kg per metric ton (the standard for new plants). These technologies are (1) catalytic reduction with natural gas, ammonia, or hydrogen; (2) scrubbing with urea/nitric acid solution; (3) extended absorption; and (4) adsorption molecular sieves.

Catalytic reduction with natural gas is a feasible and proven technology used in nitric acid plants both here and abroad. The absorber tail gas is mixed with 38 percent excess natural gas and passed over a platinum or palladium catalyst. Catalytic reduction with ammonia or hydrogen has the advantage of being selective in the sense that only the nitrogen oxides are reduced. In addition to higher costs, reduction with ammonia requires close temperature control to prevent the reformation of nitrogen oxides at higher temperatures or the formation of explosive ammonium nitrate at lower temperatures.

The tail gas can also be scrubbed, at least in principle, with aqueous urea solutions. The major products of the reaction of nitrogen oxides with urea are nitrogen, carbon dioxide, and water. Two significant factors detract from the commercial use of this process. First, the ratio of nitric oxide to nitrogen dioxide should be controlled precisely. Second, there are serious disposal problems associated with salt formation in the scrubber liquor.

Extended absorption, which has the advantage of not requiring additional natural gas, has been installed on two nitric acid plants. The industry is currently awaiting operating results from these units. Costs of extended absorption are sensitive to absorber operating pressure, which varies considerably from plant to plant. Extended absorption systems have been installed at two plants. Some industry observers believe this method will prove superior to catalytic reduction.

Molecular sieves selectively absorb the nitrogen oxides from the tail gases. The molecular sieve beds are regenerated periodically with hot gas. The NO_2-containing regeneration gas is recycled to the absorption tower.

The molecular sieve process will be tested on a commercial scale at a nitric acid plant owned by the U.S. Government. Molecular sieves are currently being installed in two additional nitric acid plants. When zeolite life becomes established in actual plant operation, it is expected that nitrogen oxide emissions abatement by this technique may become the method of choice.

Catalytic reduction with natural gas is the predominant control technology. In 1971, 10 plants producing weak nitric acid incorporated this abatement technology. About 30 to 40 percent of existing plants also employ plume decolorizers to convert visible nitrogen dioxide emissions to colorless nitric oxide. Use of catalytic reduction technology will be continued in many existing and new plants until installations using extended absorption or molecular sieves demonstrate comparable annual costs of operation. Therefore, costs of using catalytic reduction technology were taken as representative of the industry cost regardless of the technology in actual use.

Control Costs

For assessing the cost of abatement, a catalytic reduction unit (employing palladium catalyst) and two steam generators for waste heat recovery was assumed. For the base case, it was assumed that existing plants include tail-gas heaters and turbine expanders for power recovery. The investment, annualized costs, costs for selected model plants are given in Table IV-5.

The estimated nitrogen oxides emissions control costs for the nitric acid industry during the period FY 1971 through FY 1979 are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	33.8	27.4	39.9
Annual Costs			
Capital Charges	5.2	4.4	6.1
Operating and Maintenance	8.0	7.5	8.7
Total Annual Costs	13.2	11.9	14.8
Cash Requirements	89.9	82.4	99.7
New Facilities			
Investment	1.6	1.2	2.1
Annual Costs			
Capital Charges	0.3	0.2	0.3
Operating and Maintenance	0.7	0.7	0.8
Total Annual Costs	1.0	0.9	1.1
Cash Requirements	4.3	3.8	4.9

TABLE IV-5. COSTS OF CONTROL FOR SELECTED MODEL PLANTS FOR THE NITRIC ACID INDUSTRY

Model Size, 1000 metric tons/year	Investment, $1,000			Annualized Cost, $1,000/year			Unit Cost, $/ton		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
23	193	116	305	57	42	80	2.50	1.80	3.49
85	381	234	614	141	108	193	1.66	1.28	2.28
121	476	274	756	181	136	246	1.50	1.12	2.04
121	251(a)	179	314	131(a)	115	145	1.08(a)	0.95	1.20
208	633	365	981	267	202	355	1.28	0.97	1.71
340	861	526	1341	399	307	524	1.17	0.90	1.54
340	451(a)	331	566	305(a)	276	333	0.90(a)	0.81	0.98
425	988	588	1457	457	353	607	1.08	0.83	1.41

(a) New facilities.

Phosphate Fertilizer Industry

Introduction and Summary

Nature and Products and Processes. The major end products of the phosphate fertilizer industry are ammonium phosphates, triple superphosphate, normal superphosphate, and granular mixed fertilizers. Phosphoric acid and superphosphoric acid are intermediate products.

All phosphate fertilizers are processed from ground phosphate rock treated with sulfuric acid to produce either normal superphosphate or wet-process phosphoric acid. A phosphoric acid intermediate may then be reacted with ammonia to produce diammonium phosphate and other ammonium phosphates, or reacted with ground phosphate rock to manufacture triple superphosphate. Superphosphoric acid, produced by dehydration of wet-process phosphoric acid, is used in preparing some mixed fertilizers. Granular mixed fertilizers are made from either normal superphosphate or triple superphosphate, with ammonia and potash. Bulk-blended mixed fertilizers are manufactured by physically mixing particles of other fertilizer components and liquid mixed fertilizers. Bulk blends and liquids are not major sources of air pollution and are not considered in estimating the industry abatement cost.

Emissions and Control Costs. Particulate emissions from phosphate fertilizer plants (triple superphosphate, ammonium phosphate, normal superphosphate, and granulation) in FY 1971 are estimated at about 1.5 million metric tons per year. With controls, emissions can be reduced to an estimated 2800 metric tons in FY 1979.

Investment costs for control of particulate emissions in the phosphate fertilizer industry for the period from FY 1971 to FY 1979 will require an estimated investment of $19.4 million. Estimated annualized costs amount to $9.8 million.

Industry Structure

Characteristics of the Firms. The phosphate fertilizer industry is characterized by a number of large, modern efficient plants located near the source of raw materials. In general, these manufacture the more concentrated forms of fertilizer: diammonium phosphate (DAP) and triple superphosphate (TSP). These industries are particularly concentrated in Florida. Smaller plants, located near the retail markets, manufacture the less concentrated forms: granulated mixed fertilizer (NPK) and normal superphosphate (NSP). The smaller NSP, NPK, and bulk-blend plants are located in the farming states. At the beginning of 1973, there were 33 DAP plants, 13 TSP plants, 45 NSP plants, and 344 ammoniation-granulation (NPK) plants. In addition, about 5,000 bulk blending plants were operating in 1973.

The recent trend has been toward increased consumption of the higher analysis fertilizers, TSP and DAP, at the expense of NSP. The NSP plants were at an economic disadvantage with respect to transportation and economies of scale available to the large producers of concentrated phosphates, and several of these installations were shut down in the early 1970's. In 1973, however, phosphate fertilizer supply was extremely tight and all remaining NSP plants were economically producing fertilizer. Industry observers suggest that in the absence of pollution-abatement regulations, the remaining NSP plants would be viable.

Due to the seasonal demand for fertilizer, many plants manufacturing NSP and NPK operate only a portion of the year. In contrast, those plants manufacturing DAP and TSP generally operate year round.

Current Capacity and Growth Projections. Present capacity of NSP plants is estimated at 14,500 metric tons per day, well in excess of the annual production level of 3.2 million metric tons per year which has been assumed to remain constant through 1979. Similarly, capacities of NPK plants are well in excess of annual production levels of 13.6 million metric tons which have been assumed through 1979.

Annual capacity of TSP plants is estimated at 4.3 million tons and is projected to increase to 4.8 million metric tons by BY 1979, or about 19 percent of the expected growth in phosphoric acid fertilizer capacity.

Capacity of DAP plants is projected to increase from 8.1 million metric tons of 1973 to 12.1 million metric tons by FY 1979, representing 81 percent of the expected growth.

Emission Sources and Pollutants

Emissions from phosphate fertilizer processing plants are mainly fluorides (in the form of hydrogen fluoride and silicon tetrafluoride) and particulates. Fluorides are generated in the processes of acidulation of phosphate rock which contains calcium fluoride. Particulate emissions may arise from such processes as acidulation, "denning", granulation, product milling and screening, drying, and cooling.

In the phosphate fertilizer industry particulate emissions of significance originate from (1) phosphate rock grinding and beneficiation. (2) triple superphosphate manufacture, (3) [illegible]onium phosphate production, (4) normal superphosphate manufacture, and [illegible] NPK bulk blending and granulation plants.

In phosphate grinding and beneficiation, particulate emissions arise in the drying, grinding, and transfer processes. The emission factors for these processes are 7.5, 10, and 1 kg per metric ton of rock, respectively. Furthermore, 20 kg of particulate per metric ton may be lost from open storage piles.

In granular triple superphosphate production, particulate emissions may originate from a number of points in the process. Most of the particulates are given off in the drying and product-classification processes. The off-gas from the reactor (in which phosphate rock is acidulated with phosphoric acid) and the blunger (in which the reactor effluent is mixed with recycled product fines to produce a paste) may account for a considerable percentage of the total particulates emitted.

Particulate emissions from diammonium phosphate manufacture originate mainly from the granulator and the dryer. It has been estimated that the total emissions amount to approximately 20 kg per metric ton of product from both sources together.

Emissions from the manufacture of run-of-pile (ROP) normal superphosphate originate from both the acidulation and "denning" processes. Although the emission factors for particulates are not known, they are estimated to be of the order of 5 kg per metric ton.

The NPK or granulation plants manufacture a variety of products. Many different emission factors probably will apply for this class of fertilizer plant. In fixing the emission factors, these plants are assumed to employ an ammoniation-granulation process similar to that used in the DAP process, or approximately 20 kg of particulates per metric ton of product.

The emission factors given above for particulates seem to be high for triple superphosphate, diammonium phosphate, and NPK plants. The bulk of these emissions, in all three processes, most probably originate from the granulation process. There is a strong economic incentive to reduce these emissions since they contain valuable products and in many cases are associated with ammonia vapors (from the ammoniation process), the recovery of which is an economic necessity.

The following tabulation shows the estimated particulate emissions based on the factors noted above:

Fiscal Year	Mode	Particulate Emissions, 1000 metric tons TSP	DPA	NSP	NPK	Total
1971	Without Further Control	257	595	30	576	1458
1975	Without Further Control	265	720	30	576	1591
	With Further Control	5.7	0.8	0.5	1.1	2.4
1979	Without Further Control	294	910	30	576	1810
	With Further Control	0.3	1.0	0.5	1.0	2.8

Control Technology

Most of the phosphate rock of higher available phosphorus pentoxide content is ground and beneficiated to enhance its reactivity and to eliminate some of the impurities. The particulate emissions from the grinding and screening operations may be effectively controlled by employing baghouses wherein the dust is deposited on mechanically cleaned fabric filters. The dust-laden gas from the rock-drying (and perhaps defluorination) operations may first pass through a cyclone, then through a wet scrubber (such as a venturi). The efficiency of this combination should be better than 99 percent.

Particulate (and fluoride) emissions from phosphate fertilizer plants traditionally have been removed from waste gaseous streams by wet scrubbing. While efforts have been directed at removing fluorides, up to 99 percent of the particulates are simultaneously removed. Wet scrubbers of varying efficiencies have been used for this double purpose. The fluoride and particulate-laden scrubber water is usually disposed of in a "gypsum pond".

For control of particulate emissions from granular TSP plants, various wet scrubbers will be provided for a number of gaseous waste streams. The effluent from the reactor-granulator will be scrubbed in two stages. The first stage will be a cyclone and the second a cross-flow packed scrubber. The gases from the drier and cooler will be scrubbed in venturi-type packed scrubbers. Waste gases from storage of the granular product are usually scrubbed in a cyclone scrubber, although some plants use packed scrubbers. The scrubbing liquid used in all scrubbers will be recycled pond water except for the first-stage scrubbing of gases from the reactor granulator, in which weak phsophoric acid will be used and recycled to the reactor.

In DAP plants, control of particulates will be achieved for gaseous streams originating from the reactor granulator, the drier, and the cooler, together with combined gaseous streams ventilating such solids-processing equipment as elevators, screens, and loading and unloading. Two-stage scrubbing will be employed for each of the streams listed. The first stage will consist of a cyclone scrubber; the scrubbing medium will be dilute (30 percent) phosphoric acid for purposes of recovering ammonia and product. Most of the particulate matter will be removed in the first stage. The balance will be removed in the second stage consisting of a crossflow packed scrubber in which recycled pond water is used as the scrubbing medium.

It is assumed that only run-of-pile (ROP) normal superphosphate is produced in NSP plants. A cyclone scrubber will be employed in removing particulates in gaseous streams originating from the reactor-pugmill, den, and curing operation.

An ammoniation-granulation process is assumed for most NPK plants. Cyclones will be installed ahead of primary scrubbers. The primary scrubber (typically employing dilute phosphoric acid as scrubbing medium) is considered an integral part of the process in which valuable reactants (ammonia) and product are recovered.

Crossflow scrubbers have been used in estimating costs of controlling emissions of both particulates and fluorides. Most of the control technologies described above have been applied for more than a decade. Wet scrubbers of varying efficiencies have been integral parts of many phosphate fertilizer processes. The collection of waste gaseous streams and the removal of fluorine compounds therefrom has long been practiced for the health and safety of process operating personnel. Collection of particulate materials from those waste gaseous streams is dictated by economic necessity since valuable products may be involved.

In general, it can be stated that particulate controls of varying efficiency are practiced in all phosphate fertilizer processes. In some processes this control is achieved simultaneously with fluoride control. In others the incentives for control have been economic.

Control Costs

The sizes of model plants for each of the TSP, DAP, NSP, and NPK processes were obtained from the plant inventory. Each model plant represents at least one actual facility; many represent the average size plant for a number of plants in a given size category. The investment and annualized costs for these model plants (both new and existing) is given in Table IV-6. Unit costs in dollars per annual ton of capacity are also computed.

A summary of the estimated direct control costs for the total phosphate fertilizer industry (FY 1971 - FY 1979) is shown in the following tabulation:

	$ Million		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	16.9	14.9	18.5
Annual Costs			
Capital Charges	2.6	2.3	2.9
Operating and Maintenance	6.0	5.6	6.3
Total Annual Costs	8.6	7.9	9.2
Cash Requirements	36.9	34.9	38.9
New Facilities			
Investment	2.5	1.9	3.2
Annual Costs			
Capital Charges	0.4	0.3	0.5
Operating and Maintenance	0.8	0.7	0.9
Total Annual Costs	1.2	1.0	1.4
Cash Requirements	5.9	5.0	6.7

TABLE IV-6. COSTS OF CONTROL FOR SELECTED PHOSPHATE FERTILIZER MODEL PLANTS

Model Size, metric tons/year	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/annual metric ton		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Triple Superphosphate Existing Facilities									
32,000	262	194	340	135	109	162	4.25	3.42	5.09
91,000	557	396	698	252	201	301	2.77	2.21	3.31
210,000	992	735	1268	477	389	573	2.28	1.86	2.74
420,000	1621	1153	2062	805	642	969	1.93	1.54	2.32
540,000	1892	1393	2403	1004	808	1184	1.84	1.49	2.17
675,000	2095	1545	2696	1170	948	1381	1.73	1.40	2.04
New Facilities									
135,000	739	516	923	343	272	412	2.51	1.99	3.03
180,000	903	669	1130	429	345	510	2.36	1.90	2.82
Diammonium Phosphate Existing Facilities									
91,000	171	125	219	68	54	82	1.39	1.10	1.67
140,000	351	257	448	104	114	174	1.02	0.81	1.23
343,000	647	567	953	274	255	378	0.80	0.74	1.10
490,000	997	695	1277	428	316	487	0.67	0.50	0.77
635,000	1220	906	1589	547	444	667	0.60	0.48	0.74

TABLE IV-6. (Continued)

Model Size, metric tons/year	Investment $1,000			Annualized Cost, $1,000			Unit Cost, $/annual metric ton		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
New Facilities									
150,000	363	266	470	150	122	181	1.00	0.81	1.21
270,000	552	393	691	233	184	281	0.86	0.67	1.03
790,000	1150	863	1463	501	404	607	0.64	0.51	0.77
1,000,000	1342	968	1699	589	468	695	0.59	0.47	0.69
Normal Superphosphate Existing Facilities									
57,000	57	42	73	23	18	28	0.40	0.32	0.50
150,000	118	87	152	49	39	60	0.33	0.26	0.40
210,000	157	114	201	66	53	80	0.31	0.25	0.39
NPK Plants									
40,000	37			9.5			0.23		

Sulfuric Acid

Introduction and Summary

Nature of the Product and Process. About half of the sulfuric acid produced in the United States is used in the manufacture of phosphate fertilizers; the rest is used in myriad industrial applications ranging from steel pickling to detergent manufacture.

Sulfuric acid is manufactured by chemical companies and by companies engaged primarily in smelting nonferrous metals. Both sources compete for the same markets. Nevertheless, the manufacture of sulfuric acid by the smelter industry is primarily a means to reduce sulfur dioxide emissions to the atmosphere, and secondarily, an attempt to generate additional revenue. For the purposes of this investigation, smelter acid is considered to be part of the smelter industry rather than the sulfuric acid industry.

Some electric utilities may choose to manufacture sulfuric acid as a means of controlling sulfur dioxide emissions. Such utility acid is unlikely to significantly impact the market prior to 1979. In estimating emissions and costs to the sulfuric acid industry, it has been assumed that the utility industry will be generating negligible sulfuric acid.

The major products of the sulfuric acid industry are concentrated sulfuric acid (93 to 99 percent) and oleum. A few sulfuric acid plants associated with the fertilizer industry produce less-concentrated grades of acid. Essentially all sulfuric acid in the United States is currently produced by the contact process, less than 1 percent being produced by the older chamber process.

In sulfur-burning plants, sulfuric acid is produced by burning elemental sulfur with dry air in a furnace to produce sulfur dioxide. The latter is catalytically converted to sulfur trioxide. The hot converter effluent is cooled and introduced to an absorption tower where the sulfur trioxide is absorbed in a sulfuric acid solution to form more sulfuric acid by reaction with water.

Some plants (including spent-acid plants and smelter-gas plants) operate on the same principle as sulfur-burning plants except that the sulfur dioxide is obtained from the combustion of spent acid and hydrogen sulfide or from smelter off-gas. In these plants, the sulfur-bearing gas is dried with sulfuric acid and cleaned (particulate and mist removal) before introduction to the acid plant.

Emissions and Control Costs. In the manufacture of sulfuric acid, sulfur dioxide and acid mist are emitted. In FY 1971, annual emissions from all acid-plant operations (excluding smelter-gas plants) are estimated at 609,000 metric tons of sulfur oxides and 19,000 metric tons of acid mist. In FY 1979, with further controls, sulfur oxide emissions are estimated to be 64,000 metric tons and acid-mist emissions to be 10,000 metric tons.

Investment costs from FY 1971 to FY 1979 are estimated at about $400 million. Annual costs are estimated at slightly more than $100 million.

Industry Structure

Characteristics of the Firms. In 1971, 184 sulfuric acid plants reported to the Bureau of Census. Of these, 167 were contact process plants and 16 were chamber process plants. Of the 25.5 million metric tons of new sulfuric acid produced, 25.3 million metric tons was made in contact process plants. These amounts include sulfuric acid produced by the sulfuric acid industry as defined in this report and by the smelter industry. While much smelter acid is produced in the Western states, particularly in Arizona, Utah, and New Mexico, significant smelter acid is produced in Tennessee and along the Ohio and Mississippi Rivers. Sulfuric acid plants associated with the phosphate fertilizer industry are mainly located on or near the Gulf Coast and tend to be large, modern, efficient plants. The remainder of the industry is scattered throughout the United States, with a distribution approximately parallel to that for population density.

Current Capacity and Growth Projections. In 1972 production of sulfuric acid in the United States was 29.5 million metric tons, of which slightly less than 1.8 million metric tons was smelter acid. By 1975, the nonsmelter U.S. production is expected to increase to 29.5 million metric tons. By 1979, nonsmelter production of sulfuric acid is expected to reach 39 million metric tons. Here it has been assumed that all increases in production between 1975 and 1979 will be in the sulfuric acid industry and not in the smelter industry. An average industry growth rate of 4.1 percent per year was assumed. Most of the smelter acid is produced at isolated locations where long shipping distances make competition difficult. By 1977, it is expected that these smelters will have saturated the available markets.

Emissions Sources and Pollutants

Emissions from sulfuric acid plants consist of sulfur dioxide gases and sulfuric acid mist. These derive from incomplete conversion of sulfur dioxide to sulfur trioxide in the converter and from the formation of a stable mist consisting of minute particles of sulfuric acid which resists absorption in the acid absorber.

In computing the sulfur oxides and acid-mist emissions, emission factors were used in accordance with EPA specifications. The controlled emission factors for existing facilities for FY 1975 are as specified by the SIP's; there were assumed to apply both to existing and to new facilities in FY 1979. Estimated emissions for the sulfuric acid industry are:

Fiscal Year	Mode	1000 Metric Tons Per Year Sulfur Oxides	 Acid Mist
1971	Without Further Control	610	19
1975	Without Further Control	680	21
	With Further Control	154	7
1979	Without Further Control	790	24
	With Further Control	78	2.7

Control Technology

Four sulfur-emissions control processes are available for sulfuric acid plants: (1) molecular sieves, (2) the Wellman-Lord process, (3) ammonia scrubbing, and (4) two-stage (dual) absorption. Each technology is described briefly; and the advantages and disadvantages of each are discussed.

Molecular Sieves. The SO_2-bearing tail gas from the absorption tower first goes through a demister (electrostatic precipitator or fiber type) for removal of the acid mist and then through a fixed bed of pelletized specialty zeolites. The SO_2 in the gas is selectively adsorbed on the zeolite until the whole bed is saturated. The SO_2 is recovered and recycled to the acid plant and the zeolite bed is regenerated simultaneously by the passage of a stream of hot air desorbing the SO_2. In a commercial installation one bed would be adsorbing SO_2 and another is regenerating. A zeolite bed would go through many such cycles, the number of which would depend upon the degree of acid-mist removal among other factors yet unknown. One molecular-sieve-type plant is in commercial operation.

Wellman-Lord SO_2 Removal Process. The tail gas from the absorber is scrubbed with a caustic solution containing sodium hydroxide bisulfite, sulfite, and sulfate in a packed column. The main absorbant, sodium sulfite, is converted to the bisulfite as a result of the absorption of SO_2. In a recovery section, most of the bisulfite is regenerated to the sulfite by steam stripping the scrubbing solution. The SO_2 evolved in the stripping operation is recycled to the sulfuric acid train. A fraction of the regenerated scrubbing liquid is purged and the balance recycled to the scrubber after addition of appropriate amounts of sodium hydroxide solution. The purging is to avoid build up of the sodium sulfate produced by oxidation of the sulfite and reaction with acid mist. Antioxidants such as hydroquinone are added to the scrubbing liquid to help prevent oxidation.

This process has been proven in many commercial installations. The major disadvantage associated with its use for SO_2 control is the relatively high capital and operating cost. Disposal of the sodium sulfate purge stream may add to the water-pollution problem or increase the disposal costs.

Ammonia Scrubbing. The tail gas is scrubbed with an ammoniacal solution. Bisulfite, sulfite, and sulfate salts are formed in reaction with SO_2. The scrubbing liquid is then acidified with sulfuric acid and air stripped to release the absorbed SO_2 for recycle to the sulfuric acid plant. The resultant ammonium sulfate solution is disposed of in a variety of ways. Incorporation into a diammonium phosphate process has been claimed as a profitable means of disposal. Incineration to water vapor, nitrogen, and sulfur dioxides has been suggested.

Although, in principle, ammonia scrubbing has been found to be the cheapest method for SO_2 removal in sulfuric acid plants, some problems are associated with its use. Barring the use of highly efficient mist eliminators, fine particles of ammonium sulfite and bisulfite in the scrubbed tail gas may contribute to a highly visible white plume. The ability of available technology to effectively eliminate this problem remains to be fully demonstrated in long term, continuous operation.

Interstage or Dual Absorption. For an existing plant the gas from the first acid absorber is first heated (and sometimes the mist is removed therefrom) and then sent through a single-stage converter where the SO_2 is converted to SO_3. The gas from the converter is sent to an absorber and a demister before release to the atmosphere.

Dual absorption reliably met EPA standards of performance for new and modified sources in application to all types of sulfuric acid plants (sulfur-burning, smelter, and wet gas) of all sizes. In addition to controlling SO_2 emissions, dual absorption offers the added advantage of not requiring new operational skills on the part of acid plant operators. Finally, this control technology has been used in computing the SO_2 control costs for all new and existing sulfuric acid plants.

Control Costs

Existing (excluding smelter gas) sulfuric acid plants were grouped into size categories for which the total cost of control in each size category was obtained from the cost (both investment and annual) of the average size and the number of plants therein. The plant investment and annualized costs of sulfur oxides emissions control by dual interstage absorption for selected model plants are given in Table IV-7.

A summary of the estimated total cost of control in the period FY 1971 through FY 1979 in the sulfuric acid industry (apart from that produced from smelter gases) is as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	385.8	349.2	432.1
Annual Costs			
Capital Charges	59.4	53.2	65.9
Operating and Maintenance	38.1	36.0	39.5
Total Annual Costs	97.5	89.2	105.4
Cash Requirements	753.4	646.8	767.1
New Facilities			
Investment	21.4	17.2	25.0
Annual Costs			
Capital Charges	3.3	2.7	3.8
Operating and Maintenance	4.8	4.3	5.1
Total Annual Costs	8.1	7.0	8.9
Cash Requirements	45.1	34.8	45.2

TABLE IV-7 COSTS OF CONTROL FOR SELECTED MODEL PLANTS FOR THE SULFURIC ACID INDUSTRY

Model Size, metric tons/day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/ton		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Sulfur-bearing Plants									
180	1040	560	1565	260	170	345	4.32	2.83	5.73
450	1760	955	2665	460	300	635	3.03	1.97	4.18
900	2600	1400	4020	715	470	990	2.37	1.55	3.28
1,350	3400	1800	5200	955	615	1320	2.10	1.35	2.90
1,800	3980	2000	6150	1125	725	1570	1.80	1.19	2.60
1,800*	1180*	870*	1500*	470*	385*	560*	0.77	0.63	0.91
By-Product (wet-gas) Acid Plants									
180	2000	1160	2935	475	310	655	7.91		
450	3495	1830	4970	845	540	1040	5.63		
900	5415	2765	8190	1310	800	1830	4.38		
1,800	8450	4625	12700	2050	1300	2870	3.42		

* New Facilities.

METALS INDUSTRIES GROUP

Ferroalloy Industry

Introduction and Summary

Nature of the Products and Processes. Alloying elements required for making different steels often are added in the form of ferroalloys which contain iron and at least one other element. The ferroalloys are named according to the major alloying element: ferromanganese contains manganese as the additive; ferrochromesilicon contains both chromium and silicon. Another group of additives in which the iron content is very small (such as silicomanganese and silicon-chrome-manganese) are also considered as ferroalloys.

Ferroalloys are made by three methods. Submerged-arc electric furnaces are used for making most of the ferroalloys. These furnaces are of three types: open furnaces, semicovered furnaces, and sealed furnaces. Metalothermic reduction furnace production has been included with electric furnace production in the absence of sufficient information on number, location, emissions, and air-pollution-control methods. Two domestic producers use blast furnaces for making ferromanganese and (occasionally) ferrosilicon.

Emissions and Control Costs. Particulate emissions are generated during the handling of ores, fluxes, and reductant used in the production of ferroalloys. Particulates and gaseous emissions are continuously evolved during the smelting operation. Fuming occurs when the ferroalloy is poured, the amount varying with the particular ferroalloy.

Particulate emissions in the ferroalloy industry are estimated to be 137,000 metric tons in FY 1971. Emissions with additional controls are estimated to be 3600 metric tons by FY 1979.

The estimated total investment and annualized control costs for the ferroalloy industry between FY 1971 and FY 1979 are $74.3 million and $29.4 million, respectively.

Industry Structure

Characteristics of the Firms. In 1971, there were 29 companies operating 48 ferroalloy plants. The industry is composed of steel companies, chemical and mineral companies having access to particular alloying elements, and specialist producers of ferroalloys. Five companies use the metalothermic process to make specialty ferroalloys containing molybdenum, tungsten, vanadium, columbium or tantalum. Seven companies operate 10 plants for making ferrophosphorus. The remaining companies, operating 30 plants, use the submerged-arc electric furnace to produce about one-half of the ferromanganese, and virtually all of the silicon- and chromium-containing ferroalloys used in steelmaking.

Current Capacity and Growth Projections. The capacity of the ferroalloy industry is believed to be considerably in excess of production rates. Production of the six major ferroalloys in 1972 was 1,740,000 metric tons.

A growing trend toward processing ferroalloys within the country of origin has resulted in a significant loss in U.S. exports. Therefore, no growth in capacity is forecast by FY 1979, although there may be modernization programs within existing facilities to improve production methods and reduce costs.

Emission Sources and Emissions

Particulate emissions are generated during the handling of the ores, fluxes, and reductants used in the production of ferroalloys. Particulate and gaseous emissions are continuously evolved during smelting operations. Fuming occurs when the ferroalloy is poured, the amount varying with the particular ferroalloy. Submerged-arc electric furnaces of the open type are required because of the formation of crusts with certain ferroalloys; these crusts must be broken mechanically. With semicovered submerged-arc furnaces, the charge is fed to the furnace through openings around the electrodes. In open furnaces, the collection hood is raised sufficiently to provide room for charging between the hood and the charging floor; in semicovered furnaces the hood is lower and water-cooled. Open and semicovered furnaces produce greater emissions than sealed furnaces, which are used to prevent the escape of emissions and to minimize the influx of air.

Metallic silicon and aluminum are very strong deoxidizers which are used under high-temperature conditions to reduce the mineral oxides of molybdenum, titanium, zirconium, and similar metals in metalothermic reduction furnaces. This process has been included with the electric furnace production types due to the absence of sufficient information pertaining to number, location, emissions, and air-pollution control methods.

In blast furnace smelting operations, particulates and gaseous emissions are carried out of the furnace in the same off-gas stream.

Particulates emissions (in thousands of metric tons) are estimated as follows:

Fiscal Year	Mode	Particulates
1971	Without Further Control	137
1975	Without Further Control	137
	With Further Control	9
1979	Without Further Control	137
	With Further Control	3.6

Control Technology

Baghouses, electrostatic precipitators, and high-energy scrubbers are all used to control emissions from submerged-arc electric furnaces. Fumes evolving from the casting of ferromanganese in blast-furnace operations must also be controlled by baghouses.

A total of 155 ferroalloy furnaces were used in developing the model furnaces used to produce cost estimates. Only 56 furnaces could be identified as to specific ferroalloy produced and the furnace electric power rating. The distribution for these 56 furnaces was assumed to represent the size distribution for all the existing furnaces. Emissions from ferroalloy furnaces are related to the furnace electric power input.

A relationship between furnace power input and production was used to estimate furnace capacity. Capacities of open-hood and low-hood electric furnaces were related to the capacities of baghouse, scrubber, and electrostatic precipitator control devices required to satisfy the requirements.

Control Costs

The estimated control costs for four model plants using baghouse particulate control systems are shown in Table IV-8. For these model plants, the associated costs were developed both from industry and published information, and from recent EPA reports.

The estimate of the total direct cost of emissions control in the ferroalloy industry between FY 1971 and FY 1979 is:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	74.3	70.8	77.9
Annual Costs			
Capital Charges	20.6	19.9	21.5
Operating and Maintenance	8.8	8.5	9.2
Total Annual Costs	29.4	28.4	30.7
Cash Requirements	139.1	134.3	144.1
New Facilities	None anticipated		

TABLE IV-8. COSTS OF CONTROL FOR MODEL FERROALLOY PLANTS

Model Size, metric tons	Investment, $1,000			Annualized Cost, $1,000			Cash Requirements, $1,000		
	expected	min	max	expected	min	max	expected	min	max
25,000	571	512	636	314	294	337	1,555	1,477	1,638
65,000	3,748	3,428	4,172	1,109	1,003	1,230	4,622	4,244	5,116
77,000	8,863	8,049	9,680	1,915	1,747	2,093	10,222	9,314	11,111
525,000	19,911	18,662	21,186	4,269	4,005	4,550	22,931	21,594	24,337

Foundries (Iron)

Introduction and Summary

Nature of Product and Processes. Castings for machine parts, automotive parts, and soil pipe are produced from both pig iron and scrap. Cupola, electric-arc, electric-induction, and reverberatory furnaces are used. In 1972, 80 percent of the production was by cupolas, 11 percent by electric-arc furnaces, and the remainder by induction and reverberatory furnaces. The latter two types emit relatively small quantities of pollutants and require little or no emissions-control equipment.

The cupola furnace is a vertical, cylindrical furnace in which the heat for melting the iron is provided by injecting air to burn coke which is in direct contact with the charge. An electric arc furnace is an enclosed, cup-shaped refractory shell that contains the charge. Three graphite or carbon electrodes extend downward from the roof. An electric arc between the electrodes and the charge generates the required heat. Whereas the cupola melts continuously, the arc furnace operates in the batch mode.

Emissions and Control Costs. Emissions from cupolas are carbon monoxide, particulates, and small amounts of hydrocarbons. Arc furnaces produce the same kinds of emission, but to a lesser degree because of the absence of coke and limestone in the charge. Existing cupolas are required to reduce particulate emissions by an average of 95 percent. New cupolas will be required to apply 99 percent particulate emission reduction.

Estimated total annual emissions of particulates and carbon monoxide for FY 1971 are 170 and 1500 thousand metric tons, respectively. Estimates for FY 1979 (with further controls) for particulates and carbon monoxide are 5 and 210 thousand metric tons, respectively.

The estimated total investment required for the iron-foundry industry between FY 1971 and FY 1979 is $339 million. The estimated annualized cost is $180 million.

Industry Structure

Characteristics. Iron foundries may be found in almost all urban areas. The economies of scale for the industry do not prohibit the continued existence of relatively small foundries. Because many of the foundries are operated in conjunction with steel making facilities, iron foundries tend to be concentrated in the major steel-producing states: Pennsylvania, Ohio, Michigan, Illinois, and Alabama.

Iron foundries range from primitive, unmechanized hand operations to modern, highly mechanized operations. Captive plants (owned or controlled by other businesses) are more likely to be mechanized and better equipped with emission-control equipment than are noncaptive plants.

In 1972, about 5 percent of the 1470 plants were classified as large (over 500 employees), 29 percent as medium (100 to 500 employees), and 66 percent as small (less than 100 employees).

The major markets for iron castings include motor vehicles, farm machinery, and industries that build equipment for the construction, mining, oil, metalworking, and railroad industries. Captive plants have the capability of economical production of large lots of closely related castings. Most of the largest plants are captive and do not generally produce for the highly competitive open market.

Current Capacity and Growth Projections. Annual production of castings is expected to increase from 13.0 million metric tons in 1972 to 15.3 million metric tons in 1979, excluding iron molds produced for blast-furnace pig iron. The number of foundries, number of furnaces by type, and production capacities in 1972 and in 1979 are:

	1972				1979			
	Furnace Size, metric tons/hr				Furnace Size, metric tons/hr			
	40	12.9	4.0	Total	40	12	4.0	Total
Foundries	80	420	970	1,470	100	420	680	1,200
Cupolas	92	486	1,122	1,700	114	480	776	1,370
Arc Furnaces	0	164	116	280	0	246	174	420
Hot Metal, 1000 metric tons								
By Cupola	7,200	5,800	2,200	15,200	9,000	5,700	1,540	16,260
By Arc Furnace	0	1,900	230	2,130	0	2,900	360	3,240
Total	7,200	7,700	2,630	17,330	9,000	8,600	1,880	19,480
Total Industry				19,000				22,500

Production by cupolas will increase at a rate of about 1 percent per year while the total number of cupolas will decrease at a rate of about 3 percent per year. All of the decrease will be small cupolas, while the number of medium ones remains constant and the number of large ones increases. Production by arc furnaces will increase at a rate of about 6 percent per year; the number of arc furnaces also will increase at the rate of 6 percent per year.

The 80 percent of total industry production attributed to cupola furnaces in 1972 will decrease to approximately 72 percent in 1979. This decrease in cupola production will be balanced by a corresponding increase to 14 percent of the total production by arc furnaces in 1979. The total industry production will increase at the rate of approximately 2.5 percent per year. The number of foundries is expected to decrease at an annual rate of 2.5 percent.

Emission Sources and Pollutants

Emissions from cupolas are carbon monoxide, particulates, and oil vapors. Particulate emissions arise from dirt on the metal charge and from fines in the coke and limestone charge. Hydrocarbon emissions arise primarily from partial combustion and distillation of oil from greasy scrap charged to the furnace. Arc furnaces produce the same kinds of emissions to a lesser degree because of the absence of coke and limestone in the charge.

The particulate emission factor for uncontrolled cupola operation is taken to be 8.5 kg per metric ton. The best available estimate of the particulate emission factor for uncontrolled arc furnaces is taken to be 5 kg per metric ton.

An uncontrolled cupola generates approximately 150 kg carbon monoxide per metric ton of charge. Half of this carbon monoxide burns in the stack. On this basis, the estimated emission factor for carbon monoxide discharged from an uncontrolled cupola is approximately 75 kg per metric ton of charge. This emission factor is applicable to uncontrolled arc furnaces.

Estimates of total particulates and carbon monoxide emissions (in thousands of metric tons per year) for selected fiscal years are as follows:

Fiscal Year	Mode	Particulates	Carbon Monoxide
1971	Without further control	170	1560
1975	Without further control	270	2360
	With further control	5	140
1979	Without further control	290	3500
	With further control	5	210

Control Technology

For economic reasons, large cupolas use high-energy scrubbers to control the emission of particulates to acceptable levels. Medium-size cupolas can use either a high-energy scrubber or a baghouse. For small cupolas and arc furnaces, baghouses are preferred.

High-energy scrubbers usually are operated at a particulate collection efficiency of 95 percent. This efficiency can be increased to 99 percent by increasing the pressure drop. Fabric filters (baghouses) have an efficiency of 98 percent. Electrostatic precipitators also have a high efficiency, 96 percent.

Afterburners are used to control carbon monoxide emissions from cupolas and arc furnaces. The efficiency of afterburners to control that emission of carbon monoxide generally is taken to be 94 percent.

Control Costs

Estimates of control costs for selected model iron foundries are presented in Table IV-9.

The estimated total direct control costs for the iron foundry industry in the time period FY 1971 to FY 1979 are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	303	235	375
Annual Costs			
Capital Charges	46	40	59
Operating and Maintenance	114	93	150
Total Annual Costs	160	133	209
Cash Requirements	1083	922	1314
New Facilities			
Investment	36	28	47
Annual Costs			
Capital Charges	7	6	9
Operating and Maintenance	13	10	16
Total Annual Costs	20	16	25
Cash Requirements	96	83	114

TABLE IV-9. ESTIMATED COSTS OF CONTROL FOR MODEL IRON FOUNDRIES

Type of Furnace	Melting Rate, metric tons/hr	Estimated Operating Time per Year, hours	Estimated Production per Year, metric tons	Investment, $1,000			Annualized Cost, $1,000			Unit Cost $/metric ton of iron melted		
				Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Cupola	39.5	2,000	79,000	510	353	750	328	221	467	4.15	2.80	5.91
Cupola	11.9	1,000	11,900	224	162	325	119	88	169	10.20	7.39	14.20
Cupola	4.0	500	2,000	82	60	114	47	34	66	23.50	17.00	33,00
Electric arc	11.9	1,000	11,900	182	123	271	86	60	127	7.23	5.04	10.67
Electric arc	4.0	500	2,000	161	116	245	66	46	95	33.00	25.00	47.50

Foundries (Steel)

Introduction and Summary

Nature of Product and Process. The electric-arc furnace is the established equipment for the melting of steels that are subsequently poured into molds to make castings. The electric-arc furnace is a short, cylindrical-shaped furnace having a shallow hearth. Three carbon electrodes project through the furnace roof. Electric energy passing through the electrodes and into the charge creates the required heat for melting. The production sequence consists of charging the furnace, melting the charge, refining the steel, adding alloying elements, tapping the metal, and pouring the molds.

The charge consists entirely of scrap metal loaded through the opened top of the furnace. Refining is accomplished by the addition of specially prepared slag materials and by blowing the melt with high-purity oxygen when required. Ferroalloys are added to achieve the required steel composition. Prepared molds are filled with finished molten steel.

Once the steel has solidified, the castings are removed from the molds and passed on for further processing. Castings may be in a semi-finished form that requires considerable machining before use in other components, or in a high-quality product that requires a minimum of additional work before subsequent use.

Emissions and Control Costs. Particulates comprise almost the total emissions load during the production of steel castings. Minor amounts of carbon monoxide may be produced by the furnaces. Small amounts of nitrogen oxides are produced.

The estimated total annual emission of particulates in FY 1971 is 15,000 metric tons. For FY 1979 (with additional control), the estimated particulate emission is 1,720 metric tons.

Estimated total investment and annualized costs for the steel foundry industry between FY 1971 and FY 1979 are $77.2 million and $25.5 million, respectively.

Industry Structure

Characteristics. There are approximately 217 operating merchant and captive steel foundries in the United States. Steel castings are produced which vary in size from a few pounds up to approximately 250 metric tons. These foundries produce castings in alloys ranging from carbon steel through the high-alloy stainless steels. Consequently, the quantity and quality of the emissions from steel-foundry operation varies over the entire range experience elsewhere in the steel industry.

Current Capacity and Growth Projections. Production of steel castings peaked in 1966 at 1.96 million metric tons. Production in 1972 was 1.46 million metric tons. No net new steel foundry capacity is projected through 1979. Any construction will be for replacement of obsolete capacity.

Emission Sources and Pollutants

Particulate emissions comprise almost 100 percent of the emissions occurring during the production of steel for castings. Minor amounts of carbon monoxide, nitrogen oxides, and hydrocarbons may be emitted.

Most of the particulate emissions occur during the charging operation. The particulates are carried upward by the thermal gas currents created by the hot furnace. Emissions generated during the charging operation are the most difficult to control.

Small amounts of particulates are generated during the melting operation. If the melt is blown with oxygen to a great extent, the major emissions of particulates and gases may occur during this operation. Minor amounts of emissions are generated during the tapping and pouring operations.

Controlled and uncontrolled particulate emissions (in metric tons) are estimated as follows:

Fiscal Year	Mode	Particulates
1971	Without further control	15,000
1975	Without further control	15,000
	With further control	3,540
1979	Without further control	15,000
	With further control	1,720

Control Technology

Baghouses are used exclusively for the control of emissions from steel-foundry electric-arc furnaces. A general lack of space for installing the required water-treatment facilities apparently precludes the use of wet scrubbers.

Control Costs

The allowable emissions under State Implementation Plans and Federal New Source Performance Standards for steel foundries were used as guidelines in establishing the level of control required for electric-arc furnace steel foundries, and the subsequent costs.

As a means of minimizing the factors influencing the capacity of the various foundries, plant furnace-holding capacity was judged an acceptable indicator of plant capacity. A relationship based on information in the published literature was established between the plant furnace-holding capacity and estimated production capacity for foundries producing carbon steel castings, others producing alloy and stainless steel castings, and a third group producing low-alloy steel castings.

Control costs were determined for foundries producing carbon-steel castings on a one-shift basis, those producing on a two-shift basis, and those producing a three-shift basis. Control costs were similarly obtained for foundries producing alloy and stainless steel castings. Estimated control costs for selected model steel foundries are presented in Table IV-10.

The estimated total direct control costs for the steel foundry industry (FY 1971-FY 1979) are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	77.2	70.9	83.6
Annual Costs			
Capital Charges	21.4	20.2	22.7
Operating and Maintenance	4.1	3.9	4.3
Total Annual Costs	25.5	24.1	27.0
Cash Requirements	121	114	128
New Facilities		None anticipated	

TABLE IV-10. ESTIMATED COSTS OF CONTROL FOR MODEL STEEL FOUNDRIES

Model Size Range,[a] metric tons/yr	Model Size, metric tons/yr	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/metric ton		
		expected	min	max	expected	min	max	expected	min	max
180-5350										
BH-1, Carbon PENN	3,039	237	128	356	52.0	33.2	73.4	17.4	10.9	24.1
BH-2, Alloy PENN	1,975	237	219	259	57.9	54.2	62.7	29.3	27.4	31.7
BH-2, Carbon FED	3,125	171	106	263	35.0	24.8	47.8	11.2	7.93	15.3
BH-2, Alloy FED	1,873	211	133	330	46.0	33.2	63.5	24.5	17.7	33.9
5440-9890										
BH-2, Carbon PENN	6,668	483	301	693	118.0	87.7	158.0	17.6	13.1	23.6
BH-2, Carbon FED	8,991	301	172	473	63.0	43.1	90.8	7.0	4.8	10.1
BH-3, Alloy FED	6,260	317	189	461	65.5	44.9	89.7	10.4	7.17	14.3
9980-14,425										
BH-2, Carbon PENN	12,655	674	460	980	168.0	129.0	224.0	13.3	10.2	17.7
BH-2, Carbon FED	11,430	325	209	492	68.0	49.7	94.1	5.98	4.35	8.23
14,450-22,680										
BH-2, Carbon PENN	21,772	917	581	1,267	223.0	155.0	300.0	10.2	7.11	13.7
BH-3, Alloy PENN	16,329	869	590	1,255	207.0	156.0	289.0	12.7	9.54	17.7
BH-2, Carbon FED	16,329	377	245	549	80.0	58.8	101.0	4.90	3.60	6.21
27,215										
BH-2, Carbon PENN	43,091	1,530	1,420	1,672	327.0	308.0	350.0	7.59	7.14	8.14
BH-3, Carbon FED	43,545	615	421	877	131.0	98.8	175.0	3.02	2.27	4.04
108,862										
BH-1, Carbon PENN	108,862	1,610	1,480	1,733	336.0	312.0	360.0	3.09	2.86	3.31

(a) BH-1, BH-2, BH-3 refer to 1, 2, and 3 shifts per day operation. Carbon or alloy refer to the production of plain carbon steel or alloy steel (including stainless steel) castings. PENN or FED refer to air pollution control regulations in the State of Pennsylvania or Federal regulations.

Iron and Steel Industry

Introduction and Summary

Nature of the Products and Processes. The iron and steel industry for the purposes of this study is considered to consist of the following processes: sintering, coke production, blast-furnace operation, open-hearth steelmaking (OH), basic-oxygen-furnace steelmaking (BOF), and electric-arc furnace steelmaking. Other processes such as those used in iron and foundries are covered in preceding sections of this report.

Sintering is the process by which iron-ore fines and reclaimed iron dusts, sludges, and scale generated in various iron and steelmaking processes are agglomerated and prepared for charging into blast furnaces. Coking is the process used to convert suitable grades of coal to metallurgical coke for charging into the blast furnace. Blast-furnace operation is a smelting process by which iron is reduced to pig iron; and open-hearth, basic oxygen and electric-arc furnaces are used to make steel.

Emissions and Control Costs. Emissions from the sintering process are primarily particulates which are entrained in the combustion air drawn through the sinter mixture into the windowbox, or are due to transport of the sinter during the cooling operation, or are generated as dust during crushing and screening of the sinter-product. Sulfur present in the sinter mix or in combustion fuel will be emitted as SO_x.

Emissions from coking operations are particulates generated during coal preparation, coke-oven charging, coke pushing, and coke quenching; gases (H_2S, HC, CO, etc.) emitted to the atmosphere during various coking operations; and H_2S contained in the coke-oven gas produced during operation of the coke oven.

Emissions from open-hearth, basic-oxygen, and electric-arc furnaces are primarily particulates; although gaseous discharges from flashing of combustible products present in the gas are common.

Estimated emissions for the integrated iron and steel industry in FY 1971 are 3.1 million metric tons of particulates, 147,000 metric tons of SO_x, 5.4 million metric tons of CO and 153,000 metric tons of hydrocarbons. It is estimated that with additional controls, the emissions in FY 1979 can be reduced to 91,000 metric tons of particulates, 53,000 metric tons of SO_x, 463,000 metric tons of CO, and 42,000 metric tons of hydrocarbons.

The basic-oxygen furnace plant is the source of 75 percent of the particulate emissions and 99 percent of the CO emissions, while the coke plants are responsible for virtually all of the sulfur oxide and hydrocarbon emissions.

The estimated total industry control cost for the period FY 1971 to FY 1979 and the estimated cost are as follows:

	Estimated Investment ($ Million)	Estimated Annualized Cost ($ Million)
Sinter Plants	399	130
Coke Plants	852	250
Steelmaking Furnaces	788	308
Totals	2,039	688

Industry Structure

Characteristics of the Process Operations. The characteristics of the industry structure and operations for each of the processes under review are discussed below.

There are 15 companies operating 43 sinter plants ranging in size from about 180,000 metric tons per year to 4.3 million metric tons per year. Total annual capacity is estimated to be about 56 million metric tons. Sinter plants have been grouped into 14 categories based on size and applicable pollution control regulation.

Sintering consists of agglomerating (1) ore fines and (2) recleaimed iron-containing dusts, sludge, and scale generated in various iron and steelmaking processes. Sinter is made by mixing these fines with limestone and coke (or anthracite coal), charging the mixture onto a continuous traveling grate, and igniting the mixture. Air is blown through the mixture to support combustion. The sintering is complete by the time the end of the grate is reached. The sinter clinker is cooled, crushed, and screened to size for charging to the blast furnace.

There are about 60 coke plants operating in the United States ranging in size from about 220,000 metric tons to 6.4 million metric tons of coal through-put per year. The vast bulk of the coke production is owned by iron and steel companies (or affiliates). About 10 percent of the coke is produced in merchant plants for sale in the open market to foundries, other industrial users, or for internal consumption for other than steel-producing purposes.

Coking coals are received at a coal preparation facility where they are finely pulverized and mixed in the required proportions to meet specifications for blast furnace or other end uses. The prepared coal mixture is delivered to storage bunkers above the coke oven batteries. Measured quantities of the mixture are withdrawn from the bunkers and carried in lorry cars to individual ovens for charging. The coal is heated in the absence of air for a period of 14 to 18 hours to convert the coal to coke having the desired properties. During the coking cycle, volatile constituents and noncondensible gases are distilled and transferred via collecting mains to the by-products plant for the recovery of the gas and various chemicals. When the coking cycle is completed, the doors on the ends of the oven are removed and a ram pushes the incandescent coke from the oven into a quench car. The hot coke is transported to a quench tower where it is cooled under a direct water spray. The coke is then crushed and screened for use in the blast furnace or for other purposes. The fines from the crushing operation are used as a fuel in sintering operations, or are sold commercially.

Open hearth steelmaking is the oldest of the three steelmaking processes presently being used to produce raw steel. Open-hearth steel production has declined from a peak of 89 million metric tons in 1964 to 32 million metric tons in 1972. There are an estimated 22 operating open-hearth shops in the integrated iron and steel industry. It is doubtful that any new plants will be constructed. Furnace capacities range from 50 to 300 net metric tons of steel.

Average Size, 1000 metric tons/year	Number of Plants	Capacity, million metric tons/year	Percent of Total Capacity
283.5	2	0.57	2.0
982.8	3	2.95	10.4
1360.8	6	8.16	28.9
1814.4	4	7.26	25.7
3099.6	3	9.30	32.9

The open-hearth furnace is a shallow-hearth furnace that can be alternately fired from either end. The process consists of charging scrap, fluxes, and molten pig iron into the furnace where the required melting and refining operations are performed to produce the desired analysis of steel. Firing of an open hearth can be done with a variety of fuels, depending on availability, cost, and sulfur content in the fuel.

The basic-oxygen furnace (BOF) was first used to produce steel in the United States in 1955. By 1965 economic replacement of the open-hearth furnace by the BOF had been well established. BOF steelmaking expanded rapidly to about 68 million metric tons in 1972. Recently, a newer process called "Q-BOP" has been used for the commercial production of steel. This new process has been included with the BOF process for the purposes of this review.

There are 19 companies operating 38 BOF plants, ranging in size from 450,000 metric tons to 4.3 million metric tons of annual capacity. For the purposes of this study they have been grouped into four model sizes as follows:

Average Size, net metric tons/heat	Number of Plants	Capacity, million metric tons/year	Percent of Total Capacity
68-127	10	11.2	14.7
136-172	5	8.1	10.7
181-240	20	46.0	60.7
263-295	3	10.5	13.9

In BOF steelmaking, the pear-shaped, open-top vessel is positioned at a 45-degree angle and charged with the required amount of steel scrap and molten pig iron. The vessel is vertically positioned and high-purity oxygen is blown into the molten bath through a water-cooled oxygen lance positioned above the bath. Products of the oxygen reaction with the carbon, the silicon, and the manganese in the charge pass off as CO-CO_2 gases and manganese and silicon oxides in the slag. When the required content of carbon, silicon, and manganese is obtained in the melt, oxygen blowing is stopped, and ferroalloys are added as needed to attain the desired final chemical composition of the steel. The molten steel is then poured into a ladle for transfer to subsequent operations.

The electric-arc furnace has long been the established unit for the production of alloy and stainless steels. More recently, it has been widely used in mini-steel plants to make plain carbon steels for local markets. In 1972, electric-arc furnace production amounted to 15 million metric tons of stainless steel. There are almost 100 companies operating electric-arc furnace plants ranging in size from 9 thousand metric tons to 1.2 million metric tons annual capacity. For the purposes of this study electric-arc furnaces have been grouped into six model sizes as follows:

Average Size, 1000 metric tons/year	Number of Plants	Capacity, million metric tons/year	Percent of Total Capcity
45-77	11	1.0	4.0
82-127	26	2.5	10.1
136-204	21	3.4	13.4
218-340	11	3.1	12.3
363-544	21	9.1	36.1
907-1197	6	6.1	24.2

The electric-arc furnace is a short, cylindrical-shaped furnace having a rather shallow hearth. Three carbon electrodes project through the fixed or moveable roof into the furnace. Charge materials consist of prepared scrap, although one or two electric furnace shops make use of molten pig iron as part of the charge. After charging, the melting operation is started by turning on the electric power to the electrodes which are in contact with the scrap. Electrical resistance of the scrap produces heating and eventual melting of the scrap. Additional scrap is added and refining is accomplished by blowing high-purity oxygen into the molten scrap to remove carbon and silicon. Ferroalloys are added as needed to attain the desired final chemical composition of the steel. Power is shut off and the molten metal is tapped into a ladle.

Current Capacity and Growth Projections. Overall growth has been minimal in recent years as the industry has attempted modernization programs to counter the threat of increased imports. The recent growth in world demand for iron and steel has brought supply-demand relationships into better balance, but the low profit margin of the U. S. producers probably will inhibit growth of new facilities largely to replacement of existing obsolete plants for making sinter, coke, and iron.

Steel production during 1973 is estimated to be at or near what is considered a maximum available capacity of 135 million net metric tons. A consensus suggests that the requirement for all types of steel in 1980 will be approximately 160 million net metric tons, an increase of 18 percent over 1973. How will this additional capacity be obtained?

Operators of BOF shops have developed techniques to permit alternate blowing of two vessels, instead of using only one vessel while keeping the second on standby status. Two BOF shops have reported production increases of 30 to 50 percent as a result of using these techniques.

The projected production requirement for 1980 probably can be satisfied with existing BOF facilities provided techniques for the alternate blowing of vessels in two-vessel BOF shops are adopted. In addition, some BOF shops have been constructed to permit the installation of a third vessel when capacity is needed in the future.

It is judged that the modified operating procedures for two and three-vessel shops will not require the installation of additional emission-control equipment above the requirements for high-efficiency control of a single BOF vessel. The estimated costs herein are based on this assumption. It should be noted that successful implementation of these new BOF procedures will depend in part on the availability of sufficient blast furnace (pig iron) capacity.

Emission Sources and Pollutants

Sinter Plants. The emissions associated with sinter plant operation are particulates that (1) become entrained in the combustion air as it is drawn through the sinter mixture into the windbox, (2) are generated during the cooling operation, and (3) are generated during the crushing and screening operations. Sulfur contained in the fuel is not considered to be a major problem.

Coke Plants. Emissions from the production of coke occur as particulates, SO_x, CO, HC, and NO_x. Particulate emissions occur from the following sources: (1) coal receiving and stockpiling, (2) coal grinding and handling, (3) charging of coke ovens, (4) pushing the coke from the ovens, and (5) coke quenching. Gaseous emissions occur during the following operations: (1) charging the coke ovens, (2) the coking cycle, and (3) subsequent combustion of coke-oven gases.

Open-Hearth-Furnace Steelmaking. Particulates are the primary emissions occurring in open-hearth-furnace operations. Emissions of iron oxide occur during the time the scrap is melted and large quantities of iron, silicon, and manganese oxides are formed and carried into the exhaust system of the furnace when high-purity oxygen is blown into the steel bath to remove the carbon. Gaseous emissions are largely carbon dioxide, but SO_x may result through use of sulfur-containing fuels. If the scrap used in the charge contains combustibles, greater volumes of gaseous contaminants will be evolved.

Basic-Oxygen-Furnace Steelmaking. Particulates and CO are major emissions in BOF steelmaking. Particulate emissions occur at (1) the hot-metal transfer stations, (2) the flux and alloy material-handling and transfer points, and (3) the BOF vessel. Carbon monoxide and carbon dioxide are emitted at the BOF vessel.

Electric-Arc-Furnace Steelmaking. Particulates are the primary emissions occurring in electric-arc furnace steelmaking. Charging, scrap melting, oxygen blowing, and tapping are major sources of particulate emissions. Blowing the molten steel with high-purity oxygen produces the highest emission rates. Emissions from the scrap charge and other operations are similar to those from other steelmaking processes and constitute the largest portion of the total emissions.

Estimated Emissions. Estimates of emissions (in thousands of metric tons per year) are as follows:

Fiscal Year	Mode	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides	Other
1971	Without Further Control	3050	150	5460	150	1.5	8
1975	Without Further Control	3100	210	5480	210	2.0	11
	With Further Control	240	150	310	130	1.4	7
1979	Without Further Control	4340	210	8890	220	2.1	13
	With Further Control	89	53	460	42	0.5	4

Control Technology

Sinter Plants. Electrostatic precipitators, high-energy scrubbers, and baghouses are used to control the particulates originating from the sinter strand. Dry cyclones and baghouses are used to control particulates from other emission sources. Developments in blast-furnace technology which require additions of limestone and dolomite to the sinter mix make continued use of electrostatic precipitators problematical because of the difference in electrical properties between limestone dusts and iron-containing dusts. Installation of high-energy wet scrubbers may be required as replacements for some existing electrostatic precipitator installations.

Coke Plants. The technology for controlling emissions from coke ovens is still in the developmental stage; definitive control measures have not been established. Scrubbers are being used as the principal control technique for particulates in the control systems now under development. In addition to air-pollution-control devices, improved coke oven design and improved operating practice (such as sequence charging) are factors offering significant means of control. Methods used in determining estimated costs of control along with alternative techniques are discussed in detail in the section on cost methodology in the Appendix. There is some difference of opinion as to the cost of quench-tower baffle systems. The accepted industry cost has been used here.

Open-Hearth-Furnace Steelmaking. Electrostatic precipitators and high-energy scrubbers are used in controlling emissions from open-hearth furnaces. Baghouses apparently have not been used as a means of control.

Basic Oxygen Furnace Steelmaking. Electrostatic precipitators and high-energy scrubbers are the principal control systems applied to the BOF. Baghouses have been suggested for use in the United States and have been tried in Europe. Baghouses are used for collecting particulates at the hot-metal transfer stations and the flux and ferroalloy handling locations.

Electric-Arc-Furnace Steelmaking. Baghouses are the principal means of controlling particulate emissions from electric-arc furnaces. In addition, five plants of record use high-energy scrubbers; one uses an electrostatic precipitator. Means of collecting emissions from the furnace include the following:

(1) Hot gases and particulates are withdrawn through the roof of the furnace through a water-cooled duct which connects with the baghouse.

(2) A hood is placed over the furnace to collect the emissions; auxiliary hoods are used around electrode openings, pouring spout, and service doors.

(3) The entire electric-arc-furnace building is used as the collection hood for the emissions.

Combinations of these control systems, such as a combination of systems 1 and 3, are used to prevent "fugitive" emissions.

Control Costs

The cost of control for model integrated iron and steel plants are presented in Table IV-11 for five representative models:

(1) Open-hearth shop

(2) Open-hearth plus electric furnace shop (OH-Elect. Fce.)

(3) Open-hearth-basic oxygen furnace shop (OH-BOF)

(4) Basic-oxygen furnace shop (BOF)

(5) Basic-oxygen furnace-electric furnace shop (BOF-Elect. Fce.).

Note that the unit costs for control of each of the subprocesses in these five categories are not additive in terms of total steel capacity for each model.

The estimated direct control costs for the integrated iron and steel industry (FY 1971-FY 1979) are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	2,036	1,960	2,110
Annual Costs			
Capital Charges	551	534	566
Operating and Maintenance	134	131	139
Total Annual Costs	685	665	705
Cash Requirements	3,280	3,200	3,370
New Facilities			
Investment	3	3	3
Annual Costs			
Capital Charges	1.0	0.9	1.1
Operating and Maintenance	1.9	1.8	2.1
Total Annual Costs	2.9	2.7	3.2
Cash Requirements	10	10	11

TABLE IV-11. COSTS OF CONTROL FOR MODEL INTEGRATED IRON AND STEEL PLANTS

Sub-Process	Model Size net metric tons	Investment, $1,000,000 expected	Investment, $1,000,000 min	Investment, $1,000,000 max	Annualized Cost, $1,000,000 expected	Annualized Cost, $1,000,000 min	Annualized Cost, $1,000,000 max	Unit Cost, $/unit (*) expected	Unit Cost, $/unit (*) min	Unit Cost, $/unit (*) max	Control Type	Control Regulation
Open Hearth	3,200,000											
Sinter Plant	2,150,000	7.77	7.21	8.35	2.17	2.04	2.30	2.01	2.05	2.17	ESP	Federal
Coke Plant	1,870,000	17.71	16.14	19.83	3.78	3.46	4.21	2.04	1.85	2.24	Various	Federal
Open Hearths	3,200,000	18.10	16.30	20.00	3.77	3.47	4.06	1.19	1.09	1.28	ESP	Federal
Total Costs		43.58	39.65	48.18	9.72	8.97	10.57	4.08	2.78	3.21		
OH - Elect.Fce.	3,430,000											
Sinter Plant	2,450,000	3.29	2.99	3.59	0.94	0.88	1.01	0.39	0.36	0.41	ESP	Pennsylvania
Coke Plant	1,870,000	17.71	16.14	19.83	3.78	3.46	4.21	2.04	1.85	2.24	Various	Pennsylvania
Open Hearths	3,070,000	33.50	30.90	36.30	6.62	6.20	7.10	2.16	2.02	2.31	ESP	Pennsylvania
Electric Furnace	360,000	6.05	5.61	6.71	1.22	1.14	1.31	3.36	3.14	3.60	Baghouse	Pennsylvania
Total Costs		60.55	55.64	66.43	12.56	11.68	13.63	1.27	1.28	1.52		
OH - BOF	4,500,000											
Sinter Plant	1,000,000	15.60	14.60	16.90	4.34	4.07	4.67	4.35	4.07	4.68	ESP	Federal
Coke Plant	3,570,000	29.21	26.46	32.42	5.92	5.39	6.54	1.65	1.51	1.83	Various	Federal
Open Hearths	1,800,000	10.90	9.97	12.00	2.30	2.13	2.46	1.27	1.17	1.35	ESP	Federal
B.O.F.	2,720,000	1.83	1.67	2.04	1.06	0.97	1.16	0.39	0.35	0.43	Scrubber	Federal
Total Costs		57.54	52.70	63.36	13.62	12.56	14.83	3.52	3.07	3.61		
BOF	2,060,000											
Sinter Plant	380,000	6.49	5.94	7.10	1.84	1.70	2.00	4.80	4.41	5.20	ESP	Federal
Coke Plant	2,680,000	21.46	19.51	23.93	4.45	4.04	4.94	1.66	1.51	1.85	Various	Federal
B.O.F.	2,060,000	8.21	7.48	8.87	2.22	2.05	2.40	1.08	0.99	1.17	ESP	Federal
Total Costs		36.16	32.93	39.90	8.51	7.79	9.34	5.14	4.71	5.60		

TABLE IV-11. COSTS OF CONTROL FOR MODEL INTEGRATED IRON AND STEEL PLANTS (Continued)

Sub-Process	Model Size	Investment, $1,000,000			Annualized Cost, $1,000,000			Unit Cost,(*) $/unit			Control	
	net metric tons	expected	min	max	expected	min	max	expected	min	max	Type	Regulation
BOF - Elect.Fce.	4,090,000											
Sinter Plant	2,150,000	7.77	7.21	8.35	2.17	2.04	2.30	2.01	2.05	2.17	ESP	Federal
Coke Plant	2,680,000	21.26	19.51	23.93	4.45	4.04	4.94	1.66	1.51	1.85	Various	Federal
B.O.F.	3,670,000	3.25	2.97	3.59	2.02	1.86	2.20	0.55	0.51	0.59	Scrubber	Federal
Electric Furnace	220,000	4.28	3.85	4.73	0.89	0.81	0.97	2.11	1.94	2.31	Baghouse	Federal
Total Costs		36.56	33.54	40.60	9.54	8.75	10.41	2.24	2.12	2.45		

(a) Sub-process unit costs are not additive. Unit cost, net metric ton of raw steel calculated on the basis of 0.58 net metric ton of sinter and 0.77 net metric ton of coal per net metric ton of pig iron; 0.65 net metric ton of pig iron per net metric ton of open hearth steel and 0.70 net metric ton of pig iron per net metric ton of BOF steel.

Primary Aluminum Industry

Introduction and Summary

Nature of Product and Process. Aluminum metal and aluminum alloys are used in a great variety of products because of their low density, high electrical and thermal conductivity, resistance to corrosion, malleability, and high strength-to-weight ratio. Aluminum competes directly with steel, copper, magnesium, wood, plastics, and fiberglass in many of its applications. The prime markets for aluminum are building and construction, transportation, packaging, and the electrical industry.

The only commercial process for the production of aluminum is the Hall-Heroult process which involves the electrolytic reduction of alumina in a fused-salt bath. There has been recent interest in the development of new electrochemical and chemical processes.

Emissions and Control Costs. The continuous evolution of reaction products, both particulate and gaseous, from the reduction cell is the major source of air pollutants. Six states, including Oregon, Washington, Montana, Louisiana, Alabama and Maryland have regulations relating to primary aluminum production. At present, there is no New Source Performance Standard for primary aluminum smelters; the proposed New Source Performance Standard would limit fluoride emissions to 1 kg/thousand kg of aluminum produced. Fluoride emissions are reasonably well controlled at present, so that no great problem is anticipated in meeting the proposed New Source Performance Standard when it becomes effective.

Control technology for aluminum reduction cells was chosen to provide 98 percent control of particulates overall, which should meet Federal requirements.

Total industry particulate emissions for 1971 are estimated at 174,000 metric tons with existing controls. Total emissions with no further controls in 1979 would be 246,000 metric tons and 5,000 metric tons with controls.

The total industry control cost for FY 1971 - FY 1979 is $1,047 million for investments and the annualized costs are $424.1 million.

Industry Structure

Characteristics. The domestic primary aluminum industry is presently comprised of 12 companies operating 31 reduction facilities in 16 states. Three companies—Alcoa, Reynolds, and Kaiser—operate about two-thirds of the total capacity, but their dominance has been diluted during the past decade by entrance of new companies into the industry. In general, the plants are located in areas where cheap electric power is available. As a result, the plants are concentrated in the Pacific Northwest, in TVA territory, and Texas. The plant-size distribution for the industry is as follows:

Size, Thousand kg/year	Number of Plants	Percent of Capacity
0 - 90.7	6	8.8
90.8 - 136	11	28.1
136.1 - 190	8	30.8
191 - 254	6	32.3
	31	100.0

Current Capacity and Growth Projections. As of July, 1973, the rated annual capacity of the primary aluminum industry was 4,340,000 metric tons. This total rated capacity can be broken down by anode system. Presently there are 20 plants using prebaked anodes having a total annual capacity of 2,873,000 metric tons, or 66.2 percent of the total. Four plants use vertical Soderberg anodes with a total capacity of 508,000 metric tons, or 11.8 percent of the total. Horizontal Soderberg anodes are used in 7 plants having an annual capacity of 956,000 metric tons, or 22 percent of the total.

The primary aluminum industry is not a seasonal operation and prefers to operate at a relatively constant percent of capacity the year around. Over the past decade the aluminum industry has operated at an average of 92 percent of capacity.

In the past the industry has been accused of failing to expand capacity as demand rises, then building additional capacity far in excess of demand with a resultant over-capacity situation. If demand continues as forecast, there will not be excess capacity for the next several years. It is estimated that demand will grow at an annual average rate of 7 percent through 1979. This growth will require that primary production capacity grow by 1,746,000 metric tons during that time, assuming that the present relationships in components of total supply (primary ingot, domestic secondary recovery, and imports of mill shapes) continue in the future.

Production capacity will be increased to an estimated 6,085,000 metric tons by mid-1979. It is further assumed that all new plants, expansions, and replacements will use the prebaked-anode system because this system is easier and less expensive to control from an air-pollution viewpoint than is either of the Soderberg systems. Three additions to capacity have been announced, but none will be in operation before 1979.

Emission Sources and Pollutants

All primary aluminum is produced by electrolytic reduction of alumina in electrolytic (Hall-Heroult) cells. Three anode systems are used – prebaked, horizontal Soderberg, and vertical Soderberg. It is apparent that the vertical Soderberg system emits the lowest quantity of particulates, where the prebaked and horizontal Soderberg systems are higher in pollutant emissions. On the other hand, the prebaked system is easiest to control, the vertical Soderberg somewhat more difficult, and the horizontal Soderberg the most difficult to control.

The continuous evolution of the gaseous reaction products from the aluminum-reduction cell yields a large volume of fumes consisting primarily of volatile fluoride compounds, sulfur oxides, carbon monoxide, and fine dust evolved from the cryolite, aluminum fluoride, alumina, and carbonaceous materials used in the cell. The removal of this fume from the working area, as well as the requirements for cell cooling, involve extensive air-quality control that may extend to the design of the plant building and hoods, ducts, dust collectors, and gas scrubbers.

Emphasis was placed on controlling particulate emissions in this study. Based upon contacts with the aluminum industry, it is assumed that both gaseous and solid fluoride emissions are reasonably well controlled at present. Hydrocarbon emissions from the Soderberg anode systems are ignited by a burner; the combustion gases are removed from the vicinity of the cells through a duct system.

Estimated particulate emissions from aluminum smelters (thousands of metric tons) are presented in the tabulation which follows. The 1975 estimate is based on 92 percent control using the best demonstrated control technology.

Fiscal Year	Mode	Particulates
1971	Without further control	174
1975	Without further control	174
	With further control	14
1979	Without further control	246
	With further control	5

Control Technology

The control technology for each of the three anode systems was chosen on the basis that 98 percent overall control of particulates will meet Federal requirements. The states of Oregon and Washington have regulations relating to primary aluminum production. The Oregon regulation requires that visible emissions may not exceed 20 percent opacity. The Washington regulation requires that total particulate emission on a daily basis may not exceed 7.5 kg per metric ton of aluminum produced.

At the present time there is no New Source Performance Standard for primary aluminum smelters. The proposed New Source Performance Standard would limit fluoride emissions to 1.0 kg per metric ton aluminum produced. At the present time, fluoride emissions are reasonably well controlled; no unusually severe problem is anticipated in meeting the new standard when it goes into effect.

It was judged that the following control systems should meet the requirement of 98 percent control of particulates.

Cell Type	Primary Control	Secondary Control
Prebaked	Primary collection plus dry scrubber	
Horizontal Soderberg	Primary collection WESP, FBDS*, spray tower	Spray screen and water treatment
Vertical Soderberg	Primary collection FBDS, WESP, spray tower	Spray screen and water treatment

*FBDS = fluidized-bed dry scrubber

Control Costs

The cost of control for the li model plants used to compute the industry costs are presented in Table IV-12. The best available information suggests that there may be no economy of scale insofar as emission control is concerned, i.e. the unit of emission control equipment is the constant regardless of the size of the plant. For lack of additional information a constant unit cost was used to calculate industry control costs. Using a constant unit cost, the investments of emission control may be overstated for large plants and understated for small plants. The error so introduced is minimal by virtue of the symmetric distribution of plant sizes given under Industry Structure.

The following tabulation presents a summary of the estimated direct control costs for the primary aluminum industry during the period between FY 1971 and FY 1979:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	806.0	776.7	835.0
Annual Costs			
Capital Charges	113.5	110.9	116.5
Operating and Maintenance	216.9	209.6	225.1
Total Annual Costs	330.4	320.5	341.6
Cash Requirements	2464.7	2398.4	2533.9
New Facilities			
Investment	241.2	221.1	262.6
Annual Costs			
Capital Charges	34.0	31.1	37.0
Operating and Maintenance	59.7	59.7	59.7
Total Annual Costs	93.7	90.8	96.7
Cash Requirements	488.3	462.6	515.8

TABLE IV-12. COST OF CONTROL FOR SELECTED MODEL PLANTS FOR THE PRIMARY ALUMINUM INDUSTRY

Model Size, metric tons/year	Investment, $1,000,000			Annualized Cost, $1,000,000			Unit Cost, $/metric ton/year		
	expected	min	max	expected	min	max	expected	min	max
Prebaked Electrode									
70,760	9.76	8.88	10.68	3.79	3.44	4.14	48.62	44.12	53.09
110,770	15.27	13.9	16.69	5.94	5.37	6.47	48.69	44.00	53.01
167,150	22.96	21.15	25.20	8.92	8.14	9.77	48.43	44.15	53.01
232,850	32.21	28.95	34.91	12.47	11.32	13.64	48.58	44.09	53.12
Horizontal Solderberg Electrode									
70,760	23.4	21.14	25.65	10.10	9.21	11.05	129.50	118.13	141.69
110,770	36.67	33.12	39.76	15.77	14.30	17.17	129.14	117.15	140.59
167,150	55.28	50.40	60.50	23.82	21.72	25.93	129.27	117.90	140.75
232,850	77.13	69.92	84.12	33.27	36.21	36.18	129.62	117.71	140.94
Vertical Solderberg Electrode									
70,760	13.14	11.80	14.37	5.68	5.13	6.19	72.84	65.79	79.33
110,770	20.57	18.80	22.40	8.89	8.08	9.66	72.82	66.21	79.09
232,850	30.90	28.11	33.76	13.36	12.17	14.66	72.52	66.05	79.58

Primary and Secondary Beryllium

Introduction and Summary

Nature of Product and Processes. Beryl (beryllium ore) is normally recovered as a coproduct or by-product from mining of other minerals. The ore bertrandite is the only source of beryllium ore mined in the United States exclusively for beryllium content. There are two primary beryllium producers; each uses one or more of three production processes: fluoride, sulfate, and acid-leaching followed by organophosphate extraction.

Beryllium metal products are made mostly from pressed powder and are forged, extruded, and machined. Beryllia powders are pressed, extruded, fired, and machined by ordinary ceramic techniques. Finished beryllium-copper alloy products are made from melts of copper and a master copper alloy containing 4 percent beryllium. Small quantities of beryllium-nickel and beryllium-aluminum alloys are also produced. Alloy products take the form of bar, plate, rod, wire, forgings, and billets.

It is apparent that there is no distinct and independent secondary beryllium industry in the sense usually applied to the secondary nonferrous metals industries (aluminum, copper, lead, zinc, and mercury).

It is judged that the major portion of the beryllium metal and beryllium oxide wastes is being processed for reclamation by the primary producers. Admittedly, a minor fraction of beryllium-metal scrap probably is being remelted in foundry operations which are not included in the definitions of primary and secondary operations used herein.

Emissions and Control Costs. It is estimated that controlled beryllium emissions from machine shops are 8 g/day. A beryllium-alloy plant emits 13 g/day. A typical emissions factor for a beryllia-ceramic plant are 454 g of beryllium per ton of beryllium processed.

Beryllium is a hazardous air pollutant. Accordingly, the Administrator of the EPA has determined that in order to provide an ample margin of safety, emissions of beryllium dust, fume, or mist into the atmosphere should be controlled to insure that ambient concentrations of beryllium do not exceed 0.01 $\mu g/m^3$ - (30-day average).

The beryllium standard covers extraction plants, foundries, ceramic manufacturing plants, machine shops processing beryllium or beryllium alloys containing in excess of 5 percent beryllium, and disposal of beryllium-containing wastes. Most affected beryllium sources are limited to emissions of not more than 10 g/day.

Beryllium is a very expensive material, and most gas streams emitting significant quantities of beryllium are controlled with high-efficiency dry collectors. The collected material is recycled or sold back to the primary producers. Absolute filters are often used as final filters and collect small quantities of beryllium from very low-concentration gas streams. These filters are usually buried in company-owned or segregated dumps or stored in unused mines or buildings. Most of the solid wastes are prepackaged prior to burial to prevent escape of beryllium to the environment.

Although the standard is not based on economic considerations, EPA is aware of the economic impact of the standard. Since most of the sources of beryllium emissions already are controlled and in compliance with the standard, the economic impact will be very small.

On this basis, and because the total cost undoubtedly will be minimal compared to the total cost of clean air, no estimates of these costs are included herein.

Industry Structure

Characteristics of the Firms. Ninety-five percent of all beryllium metal applications are for the government, approximately one-half of which is used in nuclear weapons applications, and the other half in noncommercial nuclear reactors. Other uses include applications in electrical switchgear, electronic microcircuits and welding equipment. Manufacturing plants may be categorized as metal, alloy, and ceramic. Estimates are in the range of something over 100 metal plants, 5,000-7,000 alloy plants and something less than 100 ceramic plants.

Current Capacity and Growth Projections. Beryllium production in 1970 was about 356 metric tons. The estimated tonnage of beryllium found in the various beryllium-contained products of the primary plants is presented in the tabulation below. These amounts of beryllium equivalent by type product are considered as inputs to the various manufacturing plants:

Product Type	Equivalent Beryllium, metric tons
Beryllium billets (metal)	133
Master alloy	203
Beryllium oxide	20

Exact production figures are not published in order to avoid disclosure of the activities of individual firms. The estimates used in this report appear to be the most accurate available at the time. Production has declined in recent years; it may be that these figures are significantly high.

The National Resources Council indicates that the growth rate in the use of beryllium alloys (using 1967 as a base year) is about 5-15 percent per year.

Primary Copper Smelting Industry

Introduction and Summary

Nature of Product and Process. Copper is one of the most important of the nonferrous metals, surpassed in ore tonnage produced in the United States only by iron. Its extensive use depends chiefly upon its electrical and heat conductivity, corrosion resistance, ductility, and the toughness of its alloys. Mechanical properties (and sometimes special properties) are enhanced by alloying with zinc to form brass, with tin to form bronze, with aluminum or silicon to form the higher strength bronzes, with beryllium to form high strength-high conductivity bronzes, with nickel to form high-electrical-resistance alloys and corrosion and erosion-resistant alloys, and with lead to form bearing metals.

Principal users of copper include the electrical, electronic, and allied industries for manufacturing transmission lines, other electrical conductors, and machinery. The automobile (radiators, wiring, and bearings) and building-construction industries (tubing, plumbing) are second- and third- largest consumers of copper in the United States.

Copper ore either is surface or underground mined, concentrated by ore-beneficiation techniques, then sent to the smelter. Processing of copper concentrates at a smelter involves the following steps. Roasting normally is used to dry the finely ground concentrates and to remove some sulfur, arsenic, antimony and selenium impurities. Roasting is frequently by-passed in modern smelters because better concentration methods remove free pyrite and permit the substitution of simple dryers for roasters at some smelters. The roasted concentrate is treated in a reverberatory furnace to produce an intermediate material called matte, which nominally contains copper, iron, and sulfur. The matte is converted to impure blister copper by blowing with air or an air-oxygen mixture in a vessel called a converter to remove the sulfur and the iron. Removal of the impurities from blister copper is sometimes limited to fire refining, in which the impurities are removed in a furnace by volatilization and oxidation. More often, it entails a two step procedure: fire refining to produce electrodes for further refining by electrolytic methods.

Emissions and Control Costs. The estimated emissions of particulates and sulfur oxides are 122 and 4,300 thousand metric tons in 1971, respectively. With additional controls, the estimated emissions in 1979 would be 3,000 metric tons for particulates and 780,000 metric tons for sulfur oxides.

The estimated total investment to achieve control of particulates and sulfur oxides emission in the primary copper smelting industry is $491 million; the estimated annualized cost is $147 million.

Industry Structure

Characteristics of the Firms. The principle sectors of the primary copper industry—mining, smelting, refining, fabricating and marketing—are dominated in varying degrees by three large vertically integrated companies. In the smelting sector, four companies account for about 85 percent of the smelting capacity. The smelting sector comprises 8 companies operating 15 active smelters with a total annual smelter charge capacity of about 7.96 million metric tons, equivalent to about 1.9 million metric tons of copper metal. In early 1973, one company operated only a smelter, while eight operated both smelters and refineries. The plant size distribution for 15 active smelter operations, based on equivalent roaster charge, is shown in the tabulation below:

Capacity Range, 1000 metric tons/year	Number of Plants	Percent of Total Capacity
0-181	2	3.1
182-363	3	12.0
364-544	4	23.3
545-816	3	27.9
817-907	3	33.7

Growth Projection. Total copper production is expected to rise approximately 2 percent per year. This could rise slightly, as two new smelters are under construction; one is about three fourths completed, the other is in the engineering (planning) stage. Hydrometallurgical processes are expected to come on stream to meet need for some of this capacity during the remainder of this decade. These include liquid ion-exchange methods, direct pressure leaching of copper-iron sulfides, and the precipitation of copper powder with sulfur dioxide directly from ammonia leach solutions.

Emission Sources and Pollutants

Emissions from copper smelters are primarily particulates and sulfur oxides from the roaster, reverberatory, and converter furnaces. The density and continuity of emissions vary with the furnace type. Particulates can contain considerable by-product credits, particularly noble metals and selenium. Accordingly, part of the traditional production process is to recycle particulates up to the limit of economic viability, between 90 to 99.5 percent control, leaving the rest to be discharged as uncontrolled emission.

Sulfur dioxide is emitted from all three smelter operations; however, the concentration of SO_2 in the gases varies considerably among the three. Sulfur dioxide concentrations for fluid-solid roasters, reverberatory, and converter furnaces are 6-10 percent, 0.50-2 percent, and 2-5 percent by volume, respectively.

Estimated controlled and uncontrolled emissions of sulfur oxides and particulates for the primary copper industry are shown as follows:

Fiscal Year	Mode	Particulates, 1000 metric tons	Sulfur Oxides, 1,000,000 metric tons
1971	Without Further Control	122	4.3
1975	Without Further Control	65	4.1
	With Further Control	3.3	0.73
1979	Without Further Control	73	4.4
	With Further Control	3.6	0.78

Control Technology

Sulfur Emission Control. The various techniques being used and proposed to control sulfur oxides emission in the gaseous effluents from copper smelters have been described in detail in public literature. It is assumed that most smelters will manufacture sulfuric acid by the contact process from the sulfur dioxide in the roaster and converter gases. Two major conditions must be met: (1) the concentration of SO_2 in the gas stream should be at least 4 percent by volume, and (2) the gas must be practically free of particulate matter to avoid poisoning the catalyst in the acid plant. Ten smelters already have acid plants (one of the plants produces copper as a by-product only).

Several methods have been proposed and have been considered here for the purpose of removing the SO_2 from the reverberatory gas stream. These include:

- Absorption of sulfur dioxide in dimethylaniline, followed by desorption and recovery.
- Cominco absorption process in which SO_2 is absorbed into an ammonium sulfite solution, which yields concentrated sulfur dioxide and an ammonium sulfate by-product.
- Wet lime scrubbing, whereby the reverberatory furnace gases are scrubbed in a slurry of lime and water.
- Wet limestone scrubbing, essentially similar to wet lime scrubbing except a slurry of limestone is used as the scrubbing medium.

The assumed control technology used to estimate costs herein has been taken from unpublished EPA work which has been based upon cooperation from company engineering departments, quotations and specifications from vendors, and from announced and unannounced company plans.

Known company plans are postulated largely upon the use of surfuric acid plants for primary sulfur oxide emission control. This often requires modifications to the basic process to permit operation in the range of sulfur dioxide concentration specified above to take advantage of lower capital and operating costs for the acid plant controls. The only other technology considered here is control of sulfur dioxide emission by dimethyl-analine adsorption, followed by recovery of liquid sulfur dioxide or by conversion of the sulfur dioxide to elemental sulfur. Of the two new copper plants, it is known that one will use dimethyl-analine conversion followed by liquid sulfur dioxide recovery.

Particulate Emission Control. At present, most smelters exert a good measure of control on particulate emissions, usually by means of electrostatis precipitators. The addition of an acid plant to handle gases from the roaster and the converter requires almost complete removal of particulate from these streams prior to processing in the acid plant. In addition, a wet scrubber should be preceded by an electrostatic precipitator to prevent scrubber plugging and to permit most of the furnace dust to be returned to the smelting process or to dust by-product recovery.

Control Costs

From a statistical point of view, the 13 plants in the primary cooper industry are too few and too variable in current practice to permit the use of representative model plants for the estimation of control costs. The estimating of total industry cost of control was based on individual plant estimates. In effect, each plant becomes its own model. The model unit costs of control for three smelters which require additional control are given in Table IV-13.

The cost estimates are based on the assumption that the 13 major plants in the copper industry will meet the stated standards by employing the control methods specified in the following list:

1. Dust collection, precipitators, DMA and acid plant
2. Ambient: Roaster, reverb, converter gas handling and gas cleaning, field monitoring equipment.
   90%: Company estimate.
3. Ambient: Reverb modernization (1), converter aisle changes, gas handling and gas cleaning, acid plants.
   Local: Roasters, converter aisle changes, gas handling, and gas cleaning, acid plants, slag flotation.
   90% Sulfur Recovery: Closed-in reverbs, waste-heat boilers, gas handling and cleaning, acid plants.

4. Ambient: Converter gas handling, gas cleaning, dust collection, acid plant.
   Local: Roasting, electric furnace, converter gas handling, gas cleaning, dust collection, acid plants.
5. Ambient: Converter gas handling, gas cleaning, dust collection, acid plant, neutralization.
   Local: Converter gas handling, gas cleaning, dust collection, acid plant, neutralization, limestone scrubbing.
6. Ambient: Converters, converter gas handling, gas cleaning, dust collection, acid plant.
   Local: Electric furnace, converters, converter gas handling, gas cleaning, dust collection, acid plant.
7. Ambient: Converter gas handling, gas cleaning, dust collection, slag flotation, acid plant expansion, monitoring equipment.
8. Ambient: Converter gas handling, gas cleaning, dust collection, acid plant, neutralization, monitoring equipment.
   90%: Ambient plus lime/limestone scrubbers.
9. Ambient: Converter gas handling, gas cleaning, dust collection, acid plant, tall stack, monitoring equipment.
   90%: Ambient plus lime/limestone scrubbers.
10. Ambient: Roasters, converter gas handling, gas cleaning, monitoring equipment.
    90%: Roasters, dryer, new furnace (1), converter gas handling, gas cleaning, dust collection, slag flotation, monitoring equipment.
11. Ambient: Converter gas handling, gas cleaning, dust collection, acid plant, monitoring equipment.
    90%: Ambient plus acid plant expansion, lime/limestone scrubbing.
12. Ambient: Converter gas handling, gas cleaning, dust collection, acid plant, monitoring equipment.
    Local: Ambient plus roasters, acid plant expansion, slag flotation, furnace modernization.
    90%: Ambient plus closed-in furnaces, DMA scrubbers, SO_2 plant, elemental sulfur plant.
13. Ambient: Converter gas handling, gas cleaning, DMA scrubbing, liquid SO_2 plant, monitoring equipment.
    Local: Ambient plus closed-in reverb, gas cleaning, DMA scrubbing, SO_2 plant, elemental sulfur plant.

The estimated direct control costs for existing facilities of the primary copper industry during the period FY 1972 through FY 1979 are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	491	449	539
Annual Costs	147	138	156
Capital Charges	84	78	89
Operation Maintenance	63	60	67
Cash Requirements	1089	1025	1162
New Facilities	N/A[(a)]		

(a) New nonpolluting process technology will be emphasized.

These estimates have been derived as nearly as is possible from the detailed costing and statistical procedures used in this work, and are based in part on an estimate of the probable range of costs as specified above.

TABLE IV-13. COSTS OF CONTROL FOR THE MODEL PLANTS IN THE PRIMARY COPPER INDUSTRY

Model Size,[(a)] Metric tons/Year	Investment, $1,000,000			Annualized Cost, $1,000,000			Unit Cost, $ per daily metric ton furnace charge		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Expected	Minimum	Maximum
227,000	22.8	17.8	28.7	6.3	5.0	8.1	27.75	22.03	35.68
544,000	42.0	32.3	53.1	12.3	9.4	15.6	22.61	17.28	28.68
907,000	55.3	51.1	86.0	19.1	15.1	25.0	21.06	16.65	27.56

(a) Furnace Charge.

Primary Lead Industry

Introduction and Summary

Nature of Product and Process. Lead is the third most important nonferrous metal, surpassed only by aluminum and copper in ore tonnage produced in the United States. The extensive use of lead depends chiefly upon its corrosion resistance, density, malleability, alloying properties, and its chemical compounds.

Lead products are vital to the U.S. economy. Lead acid batteries are indispensable to the motorized industry and society. These require great quantities of lead, in the range of 30-40 percent of total consumption. Cable coverings, building construction, solder, type metal, and bearing metal in total are almost equally critical and demanding of lead supplies. Paint pigments and tetraethyl lead in gasoline have been important chemical uses; they accounted for 73,000 and 240,000 metric tons, respectively, out of a total of 1,297,000 metric tons consumed in the U.S. in 1971. Both uses have been cited as environmental hazards which have resulted in depressing the market for lead. This depression is expected to be partially compensated for by expanded demand in other uses. The U.S. Bureau of Mines "Low" forecast which takes into account the loss of these markets for lead, is 2.3 million metric tons by the year 2000.

Emissions and Control Costs. The major emissions from lead smelters are particulates and SO_2 from two sources: sintering machines and blast furnaces. Estimated emissions in FY 1971 were 440 metric tons of particulates, and 99,300 metric tons of sulfur oxide. Estimates for FY 1979, with further controls, are 300 metric tons of particulates and 21,200 metric tons of sulfur oxide.

For the period beginning 1971 and ending 1979, the expected cash requirement for existing facilities will be $51 million, the expected investment will be approximately $27 million, while annualized costs in 1979 will be about $6.8 million. There are six lead smelting plants, only three require acid plants in order to meet emission standards. The remaining smelters already have acid plants.

Industry Structure

Characteristics of the Firms. As many as 300 companies have comprised the overall primary lead industry in the U.S.; i.e., mining, smelting, refining, and marketing. Now, however, the industry is dominated by a relatively few companies, of which one, St. Joe Minerals, is vertically integrated from mine through marketing, and two others, Amax and Asarco, are vertically integrated from smelter through marketing.

In the smelting sector, U.S. smelters currently process about 1,297,000 metric tons of concentrate to produce 637,000 metric tons of pig lead. In terms of feed charge, however, the capacity is much more than this but some of the capacity is obsolescent. The silver-bearing ores of the Western states comprise about 10 percent of supply, and are treated at lead/silver smelters and refineries in Idaho, Montana, Texas, and Nebraska. The remainder, the nonsilver ores of Missouri, are processed at soft-lead smelters and refineries in Missouri.

Four companies control the entire capacity: Asarco, St. Joe, Amax, and Bunker Hill.

Secondary lead processing, which is to recover scrap lead, has about equalled U.S. mine production for the past several years. Both primary lead smelters and scrap resmelters participate in secondary lead recovery.

Current Capacity and Growth. The product of lead smelting and refining is pig lead suitable for rolling into sheet, casting, alloying, and converting into high-purity oxide and chemicals. Primary lead production in 1972 was as follows: Asarco 208,000 metric tons; St. Joe 189,000 metric tons; Amax 121,000 metric tons; and Bunker Hill 120,000 metric tons.

Lead consumption in 1973 is estimated at 1,248,000 metric tons, up 3 percent over 1972. The major consumer of lead is the transportation industry for lead batteries and gasoline additives. Other using industries are construction, electrical machinery and products, and paint and varnish, typically as follows:

Industry	Percent Consumption
Storage batteries	29
Gasoline	17
Construction	9
Cable covering	4
Paint and varnish	2
All other	39
Total	100

Gasoline consumption, paint/varnish, and cable covering are under downward consumption pressures, while storage batteries and construction are upward. Total consumption is expected to grow between 1 to 3 percent per year during the 1970's, without any need for additional smelting capacity. This growth rate takes into account reductions in use for gasoline, paints, and cable covering. Mining capacity is expected to increase, however, displacing imports. After a five-year period of growth in mining capacity in Missouri, little additional growth is expected. However, in 1973, St. Joe will add 59,000 metric tons per year in underground mining and concentrating capacity in Missouri.

Emission Sources and Pollutants

Emissions from lead smelters are primarily particulates and SO_2 from two sources: sintering machines and blast furnaces. Most of the sulfur is removed in the sintering machine. The density of emissions varies with the source.

Flue-gas particulates contain as high as 30 percent lead, as well as zinc, antimony, cadmium, and copper, and in western smelters, often significant by-product credits of noble metals; in one case over 30 ounces of silver per ton and 0.14 ounce of gold. Thus, there is an economic reason to recover particulates in addition to that of fume control. The emissions from the slag furnaces used in the Western U.S. smelters to recover zinc yield particulates containing zinc oxide and zinc dust. These were accounted for in the emissions reported in industry questionnaires.

Fiscal Year	Mode	Particulates, metric tons	Sulfur Oxides, metric tons
1971	Without further control	440	99,300
1975	Without further control	440	99,300
	With further control	300	21,200
1979	Without further control	440	99,300
	With further control	300	21,200

Control Technology

Sulfur oxide and particulates in sintering machine off-gases are being controlled by the use of sulfuric acid plants in three of the six U.S. smelters. In these smelters, particulate control is required in order that the acid-plant systems function effectively.

In the three U.S. smelters without acid plants, most of the particulates in the processing off-gases are removed from the cooled off-gases in a baghouse prior to the stack; sulfur oxide in the off-gases is not controlled. (One of these has an acid plant which is used only on the off-gases from a copper converter in an adjoining plant.)

Control Costs

Each of the six U.S. plants was examined in terms of equipment required to bring the plant within Federal control standards. Acid plants were assumed for those plants which do not now control sulfur oxides emissions. Methods of metallurgical operation at all six plants are similar, the differences stem from the type of ore handled by the three Missouri smelters and by the three Western U.S. smelters. In the West, concentrates are leaner with much higher amounts of gold, silver, zinc, cadmium, copper, antimony, and arsenic present. Except for a slag-fuming furnace operation in the Western smelters to remove the higher amounts of zinc in the concentrates, there are no major differences in the basic smelter operations. There is a difference in degree in the refining operations, but off-gases are not a problem in the refineries. Refining involves kettle operations at low temperatures just above the melting point of lead. There are no fumes produced.

Estimated costs of control for model plants are presented in Table IV-14.

TABLE IV-14. COSTS OF CONTROL FOR SELECTED MODEL PLANTS FOR THE PRIMARY LEAD INDUSTRY

Model Size, metric tons/ year (sinter charge)	Investment, $1,000,000			Annualized Cost, $1,000,000			Unit Cost, $/metric ton of annual capacity		
	expected	min	max	expected	min	max	expected	min	max
107,000	8.9	4.3	12.5	2.1	1.0	3.0	17.8	8.8	26.3
131,000	9.9	5.1	13.8	2.5	1.2	3.4	17.4	8.3	23.6

The estimated total direct costs of control in the primary lead industry during the period FY 1971 through FY 1979 are:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	27.3	16.8	38.6
Annual Costs			
Capital Charges	4.4	2.7	6.3
Operating and Maintenance	2.4	1.4	3.2
Total Annual Costs	6.8	4.1	9.5
Cash Requirements	51.0	35.6	64.4
New Facilities		None anticipated	

Primary Mercury Industry

Introduction and Summary

Nature of Product and Process. Cinnabar ore is surface or deep mined, crushed, screened, and roasted in a rotary kiln. Mercury vapors leave the kiln in the hot combustion gases. Mercury metal is recovered by condensation in an air-cooled heat exchanger. Prime virgin liquid mercury metal is separated from the accompanying flue dust by treatment with lime on a hoe table. U. S. Bureau of Mines pilot plant tests on a patented electro-oxidation process on cinnabar show promise but, as yet, the process is not commercial.

The mercury market has been severely depressed in recent years by the abundance of relatively cheap prime virgin mercury of foreign origin, and by decreased usage in the U. S. as a result of efforts to limit mercury emissions to the environment.

Emissions and Control Costs. Mercury emissions in the form of vapor and mist are confined almost entirely to the discharge of stack gases from the system after the major portion of the mercury vapor from the kiln is removed in the condenser. In order to meet EPA hazardous-emission regulations of 2300 grams per day of mercury, the users of mercury cells will be required to reduce mercury emissions by approximately 95 percent. Based on the assumption that the eight subject plants operate at full capacity, the estimated emissions are 50-60 metric tons per year in FY 1971, and 3 metric tons per year in FY 1979 with further controls.

Total investment costs for the control of eight major plants are estimated to be $0.88 million. Annualized costs are estimated at $0.22 million, with a total cash requirement for the period FY 1971-FY 1979 of $1.66 million.

Industry Structure

Characteristics. The following tabulation presents statistics related to the primary mercury industry:

	1967	1968	1969	1970	1971	1972
Number of Producing Mines	122	87	109	79	30	21
Average Price per flask, $	489	536	505	408	292	218
Production, flasks at 34.5 kg	23,800	28,900	29,600	27,300	17,400	7,290
Consumption, flasks	69,500	75,400	77,400	61,500	52,700	52,900

A sharp decrease in domestic production beginning in 1970 has continued through mid-1973. Primary mercury production during the remainder of this decade probably will be depressed as a result of abundant foreign supply, decreased domestic demand, and the high cost of production from relatively poor domestic ores.

Current Capacity and Growth Projection. The ore-processing capacity of eight major producers of prime virgin mercury is as follows:

Capacity Range (Ore-Processing), metric tons/day	Number of Plants	Percent of Total Capacity
0 - 68.0	1	4.0
68.9 - 136	4	29.7
137.0 - 272	2	38.2
273.0 - 544	1	28.1
	8	100.0

Six of these plants are in California, and there is one each in Idaho and Nevada.

Mercury consumption in the U. S. declined significantly in 1970, 1971, and 1972. Major mercury users in 1972 include manufacturers of electrical and measuring apparatus (29 percent), electrolytic preparation of chlorine and caustic soda (22 percent), antifouling and mildew proofing for paint (16 percent), and industrial and control instruments (12 percent). The use of mercury in mildewcides and antifouling paint is expected to be substantially reduced in the future. The implementation of mercury-emission control in chlorine/caustic manufacture has and will continue to reduce significantly the demand for virgin mercury by this industry. New capacity for chlorine manufacture will not use mercury cells, with the exception of one new plant scheduled for startup in the first quarter of 1974.

The U. S. primary mercury industry is in a state of flux as the result of low prices and slackened demand brought about by the cancellation of biocidal and cosmetic uses of mercury and by the implementations of mercury-emission controls. The eight plants included in the tabulation above for which control costs were estimated in this report, operated only intermittently; not more than two or three of these are operating at the present time. Their capacity is such that they could process annually about 27,000 metric tons, the rate of production in the 1968-1970 period.

Emission Sources and Pollutants

Mercury ore is processed almost exclusively by roasting in rotary kiln equipment. The major portion of mercury vapor, which leaves the kiln in the hot combustion gases, is recovered in air-cooled condensers. The major source of mercury emissions in primary processing operations is the partially cooled and treated stack-gas discharge to the atmosphere.

The hazardous pollutant, mercury, is the only pollutant considered here. Relatively minor sulfur emissions from the ore and from the combustion of sulfur-bearing fuel oils, and nitrogen oxides emissions from the combustion process are not considered.

The maximum estimated mercury emissions in units of metric tons are given below:

Fiscal Year	Mode	Mercury
1971	Without Further Control	50-60
1975	Without Further Control	14.7
	With Further Control	3.0
1979	Without Further Control	14.7
	With Further Control	3.0

It was assumed that in FY 1971, 30 plants operated at full capacity. For FY 1975 and FY 1979, a maximum emission was computed on the assumption that the eight major installations will operate at full capacity.

Control Technology

Two emission-control systems are judged to be applicable over the full range of situations and plant operating conditions which are expected through 1979:

- Cooling to 13 C (55 F) followed by mist elimination
- Wet scrubbing to 13 C (55 F) outlet temperature.

All necessary equipment is commercially available at the present time. A necessary degree of flexibility in application of emission controls to a specific plant situation is provided by the choice of these two systems. In three cases, only high-efficiency demisting equipment is needed.

Control Costs

Cost computations were performed on a plant-by-plant basis, so that each of the eight plants is its own model. For three representative plants, the investment, annualized cost, and unit costs of control are shown in Table IV-14.

TABLE IV-14. COSTS OF CONTROL FOR THE MODEL PLANTS IN THE PRIMARY MERCURY INDUSTRY

Model Size, metric tons per day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/metric ton/day		
	expected	min	max	expected	min	max	expected	min	max
45	27	22	33	7.3	6.0	8.7	0.16	0.13	0.19
158	149	127	173	39	30	49	0.24	0.19	0.30
318	221	184	254	65	51	78	0.21	0.16	0.24

The estimated direct control costs for the primary mercury industry during the period FY 1971 through FY 1979 is as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	0.877	0.823	0.946
Annual Costs			
Capital Charges	0.142	0.134	0.154
Operating and Maintenance	0.081	0.067	0.097
Total Annual Costs	0.224	0.201	0.251
Cash Requirements	1.66	1.52	1.78
New Facilities	None anticipated.		

All costs have been computed on the basis that the eight major plants will operate at full capacity through 1979. The computed cost therefore is a maximum which can be interpreted as the investment and annualized expenditure that will be required to restart the primary mercury industry.

Primary Zinc Industry

Introduction and Summary

Nature of Product and Process. Among the nonferrous metals produced in the U. S., zinc ranks fourth in tonnage after aluminum, copper, and lead. The manufacture of galvanized-steel products provides the major demand for pure zinc. Zinc sheet is used in the manufacture of dry cells, and for building-construction materials. Zinc-alloy die castings find major uses in automobile parts, electrical and electronic equipment, lighting fixtures, and office equipment. Zinc alloys with copper to make brass for use in armaments, electrical fixtures, marine hardware, and construction. Zinc chemicals find important uses in pigments, agricultural preparations, rubber, and paper.

There are three major processing steps in the manufacture of zinc:

- Mining
- Ore concentration
- Elimination of metal production

Sulfide ore concentrate is roasted to produce the oxide; the sulfur leaves as sulfur oxide in the roaster gas. Calcines are sometimes sintered into briquets which in a pyrometallurgical plant are sent to the reduction furnace to produce zinc metal.

Emissions and Control Costs. Emissions from the zinc reduction plant are primarily particulates and sulfur oxide from the roaster and sintering furnaces in the pyrothermic plants, and from fluid-bed roasters in the electrolytic plants. In FY 1971, particulate emission amounted to 18,600 metric tons and sulfur oxide emission amounted to 263,000 metric tons, without control. In FY 1979, with further control. the estimates are 1900 metric tons of particulates and 31,000 metric tons of sulfur oxide.

The expected cash requirement for existing facilities is $60.7 million, with an investment requirement of $32.4 million and a total annualized cost of $8.15 million.

Industry Structure

Characteristics of the Firms. The major portion of zinc ore is produced from relatively few mines in eight states: Tennessee, Colorado, Missouri, New York, Idaho, New Jersey, Utah, and Pennsylvania. Generally, eastern ores are lower grade but less complex; western ores are higher in zinc, lead, and noble metals in complex mineralization.

Custom reduction plants purchase and process ores and concentrates to slab zinc. Custom plants also provide toll-conversion service for independent mine operators. Vertically integrated producers own mines as well as smelters. Of the 14 plants operating in the U. S. in 1968, eight are in operation through 1973. Accordingly, control procedures advocated here are based on the industry practice during this period. It was recognized that at least one of the plants which did not have an adjacent acid plant would be closed in the near future, but since it would, no doubt, be replaced, it was necessary to include it so as to arrive at a conservative estimate. The plant size distribution for these eight plants is tabulated below:

Capacity, 1000 tons concentrate per year	Capacity, 1000 metric tons per year	Number of Plants	Percent of Total Capacity
0-100	0-90	2	13.3
101-200	91-180	4	47.4
201-400	181-360	2	39.3
		8	100.0

Current Capacity and Growth Projection. The product of the zinc reduction plants is slab zinc. Ore concentrate capacity in 1973 is 1,331,000 metric tons per year, equivalent to 934,000 metric tons slab zinc. Approximately 10 percent of this capacity utilizes horizontal retort plants. All of these will be phased out by July, 1975.

In 1973, pyrothermic plant production will account for more than one-half of capacity, electrolytic plants will account for the remainder. Production has been diminishing in recent years, and is not expected to increase in the next two years. Consideration is being given to the construction of two new electrolytic plants, one in Kentucky, and one in Oklahoma.

Emission Sources and Pollutants

Emissions from zinc-reduction plants are primarily particulates and SO_2 from the roasters and sintering furnaces. Pyrothermic plant practice is to remove most of the sulfur from the concentrates in the roaster, and complete the oxidation of the zinc in the sintering machine. In the electrolytic plants the calcine from the roaster is substantially sulfur free. Therefore, heavy concentration of SO_2 appears in the roaster off-gases and in the case of the pyrothermic plants, light concentrations of SO_2 in sintering off-gases. Particulates are relatively heavy in both streams.

Current emissions above the level of control achieved prior to FY 1971 and for full-capacity operation of the industry are given (in 1000 metric tons) in the following tabulation:

Fiscal Year	Mode	Particulates	Sulfur Oxides
1971	Without further Control	18.6	263
1975	Without further Control	18.6	263
	With further Control	1.9	31
1979	Without further Control	18.6	263
	With further Control	1.9	31

In FY 1971, approximately 90 percent of the particulates emissions were being controlled.

Control Technology

Sulfur oxide and particulates in roaster off-gas currently are being controlled by the use of sulfuric acid plants in 5 of the 8 plants of interest. In these cases, particulate control is required in order that the acid plant systems function effectively.

off-gas streams are treated separately. Particulate control can be obtained by the use of electrostatic precipitators or baghouses (fabric filters). Sulfur emissions from the sinter operation must be controlled where necessary with scrubbers.

Control Cost

Each of the eight plants was looked at in terms of equipment needed to bring the plant to within Federal control standards. Acid plants were recommended to control heavy SO_2 emissions for three plants where acid plants now are absent. Particulate control is also required for these plants. For sinter streams where the particulate loading still fell short of Federal Standards three baghouses and two ESP's, were recommended.

The model plant costs and unit costs are given in Table IV-15. The summary of estimated total direct control cost for the primary zinc industry in the period FY 1971 through FY 1979 is as follows on the next page.

TABLE IV-15. COSTS OF CONTROL FOR THE MODEL PLANTS PRIMARY ZINC INDUSTRY

Model Size,* Metric Tons	Investment $1,000,000			Annualized Cost, $1,000,000			Unit Cost, $/unit*		
	expected	min	max	expected	min	max	expected	min	max
91,000	8.67	6.66	11.1	2.17	1.65	2.77	23.8	18.1	30.4
139,000	11.6	8.82	15.0	2.91	2.23	3.76	20.9	16.0	27.1
149,000	12.2	9.42	15.6	3.09	2.37	3.97	22.2	17.1	28.6

* Metric Tons per year to roaster.

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	32.4	27.3	39.6
Annual Costs			
Capital Charges	5.26	4.45	6.45
Operating and Maintenance	2.89	2.46	3.55
Total Annual Costs	8.15	6.91	10.0
Cash Requirements	60.7	53.4	69.6

New Facilities: 2 Electrolytic Plants are under consideration, one in Kentucky, the other in Oklahoma. But these plans are still in the early tentative stages.

Secondary Aluminum Industry

Introduction and Summary

Nature of Product and Process. Aluminum has become one of the most important metals in industry; only iron surpasses it in tonnages used. Major uses of the metal are in the construction industry, aircraft, motor vehicles, electrical equipment and supplies, beverage cans, and fabricated metal products which include a wide variety of home consumer products. The automotive industry is a large user of secondary aluminum ingot.

Secondary aluminum ingot is produced to specification; melting to specfication is achieved mainly by segregating the incoming scrap into alloy types. The magnesium content can be removed with a chlorine-gas treatment in a reverberatory furnace.

For the purpose of this report, the secondary aluminum industry is defined as that industry which produces secondary aluminum ingot to chemical specifications from aluminum scrap and sweated pig. The industry is viewed as consisting of secondary aluminum smelters excluding primary aluminum companies, the activities of nonintegrated fabricators, or scrap dealers.

Emissions and Control Costs. Major emissions from secondary aluminum smelters are products from the volatization or oils, paint, and other coatings on borings, and turnings during the drying process; fluorides and particulates from fluxes in the sweating and reverberatory furnaces; and chlorine from chlorine-gas treatments in reverberatory furnaces.

Estimated particulates emissions from aluminum secondary smelters are 5340 metric tons in FY 1971, and 2268 metric tons in FY 1979 with further controls.

The expected cash requirement for new and existing facilities is $44.4 million with an investment requirement of $18.6 million, and a total annualized cost of $5.7 million for the period FY 1971 through FY 1979.

Industry Structure

The secondary aluminum industry, as defined above, consists of an estimated 54 firms with 65 plants. Although most sources list the industry as having more plants, their data usually include sweaters, scrap dealers, and nonintegrated fabricators.

Of the total estimated industry capacity of slightly over 1 million tons per year, the top four firms account for about 50 percent of the capacity.

The growth in estimated production of secondary aluminum ingot has increased at the average rate of 5.3 percent annually for the period 1963 to 1971. It is estimated that future growth in production and capacity will continue at this average rate.

Emission Sources and Pollutants. The most serious emissions in secondary aluminum smelting occur in (1) the drying of oily borings and turnings, (2) the sweating furnace, and (3) the reverberatory furnace. Emissions from (1) are vaporized oils, paints, vinyls, etc; from (2) are vaporized fluxes, fluorides, etc; from (3) are emissions similar to (1) and (2) plus HCl, $AlCl_3$, and $MgCl_2$ from the chlorine gas treatment to remove magnesium. As of 1970, an estimated 25 percent of chlorination station emissions were controlled. By 1979, it is estimated that 80 percent of the chlorination stations will be controlled. The following tabulation is an estimate of the particulate emissions for the 1971-1979 period:

Fiscal Year	Mode	Particulates, metric tons
1971	Without further control	5,340
1975	Without further control	6,940
	With further control	2,780
1979	Without further control	8,500
	With further control	2,270

Control Technology and Cost

Dryer emissions are known to exist and in many cases are treated with afterburners; however, there are insufficient data relating to the drying operations to permit evaluations of possible costs that might be expended to meet air-quality specifications.

Sweating-furnace emissions, fluroide from fluxes, organic materials, oils, etc., can be controlled through the use of afterburners followed by a wet scrubber or baghouse, and control costs have been reported; however, no data are available on the number, capacity, or location of sweating furnaces. Thus, a realistic estimate of control costs cannot be made.

There are several processes which cause emissions during the operation of a reverberatory furnace. These must be understood to calculate control costs properly. They are:

(1) Emissions at the Forewell--Secondary smelters charge scrap directly into the forewell of the reverberatory furnace. Any oil, paint, vinyl, grease, etc., on the scrap vaporizes. The emissions from the charging process vary greatly with the material charged. Quantitative data on forewell emissions or the need for control are not available and costs or possible costs cannot be estimated.

(2) Emissions from the Bath--During the time the aluminum bath is molten, it is covered with a flux to protect it from oxidation.

(3) Emissions Caused by Chlorination--The magnesium content of a heat of aluminum can be reduced by chlorination. Chlorination produces emissions of HCl, $AlCl_3$, and $MgCl_2$. Particulate emissions from the chlorination process are 1,000 pounds per ton of chlorine used. Maximum magnesium removal requires about 40 pounds of chlorine per ton of aluminum which has an emission rate of 20 pounds of particulates per ton of aluminum. Magnesium removal is practiced by plants representing 92 percent of the estimated industry capacity. A small portion of these plants use aluminum fluoride fluxing for magnesium removal, rather than chlorine. It is assumed here that control costs for these few plants are similar to those that use chlorination. Wet scrubbing is the usual means of controlling chlorination station emissions. Recent innovations on a dry control process are being tested.

Control Costs

For the purpose of estimating chlorination control costs, the identified secondary smelters were classified into three model plant categories based on estimated capacity. The following tabulation shows the basis upon which this was done:

Model Group Number	I	II	III	Industry Total
Capacity Range, short tons per year	3,000-11,999	12,000-29,999	30,000-70,000	3,000-70,000
Capacity Range, metric tons per year	2,722-10,885	10,886-27.215	27,216-63504	27,222-63,504
Number of Plants	26	20	12	58
Capacity, metric tons per year	112,660	342,470	511,160	966,780
Member of Plants Practicing Magnesium Removal	13	20	11	44
Capacity Subject to Magnesium Removal, metric tons/year	68,500	342,500	479,000	890,000
Model Plant, Average Capacity, metric tons/year	5,260	17,125	43,550	--
Model Plant, Average Capacity, metric tons/day	21.0	76.4	174	--

The estimated capital cost and annual cost for control of emissions from the chlorination station for each of the model plant sizes chosen are shown on Table IV-16.

Estimates of the investment in control equipment, annual costs, and cash requirements for the secondary aluminum industry for the period FY 1971 through FY 1979 are given in the tabulation below.

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	14.1	12.0	17.9
Annual Costs			
Capital Charges	1.85	1.62	2.20
Operating and Maintenance	2.41	2.07	2.80
Total Annual Costs	4.26	3.69	5.00
Cash Requirements	35.6	31.4	40.1
New Facilities			
Investment	4.45	3.64	5.50
Annual Costs			
Capital Charges	0.58	0.49	0.71
Operating and Maintenance	0.88	0.75	1.08
Total Annual Costs	1.46	1.24	1.79
Cash Requirements	8.84	7.77	10.6

TABLE IV-16. COSTS OF CONTROL FOR SELECTED MODEL PLANTS FOR THE SECONDARY ALUMINUM INDUSTRY

Model Size, metric tons/year	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $ per metric ton of annual capacity		
	expected	min	max	expected	min	max	expected	min	max
5,260	188	156	236	50.0	41.4	62.5	9.51	7.87	11.88
17,150	280	213	394	81.1	64.1	107.0	4.73	3.74	6.24
43,550	539	457	684	180.0	151.0	228.0	4.13	3.47	5.24

Secondary Brass and Bronze

Introduction and Summary

Nature of Product and Process. Brass is a copper alloy in which the major alloying element is zinc. Bronze is a copper alloy in which the major alloying element is tin. The secondary brass and bronze industry may be divided into two segments: ingot manufacturers and brass mills. Not all brass mills have a casting department.

Both segments of the industry charge scrap into a furnace where it is melted and alloyed to meet specifications for chemical composition. Ingot manufacturers use either a stationary reverberatory furnace or a rotary furnace for most of the production. Small quantities of special alloys are processed in crucible or electric induction furnaces. A few cupolas exist in which highly oxidized metal, such as skimmings and slag, is reduced by heating the charge in contact with coke. Ingot manufacture invariably requires injection of air to refine the scrap. Brass mills use scrap that does not require such extensive refining. The channel induction furnace is the most common type used by brass mills.

Emissions and Control Costs. Metallurgical fumes consisting chiefly of zinc oxide and lead oxide are the major emissions from reverberatory, rotary, and induction furnaces. Total industry emissions are estimated at 9740 metric tons in FY 1971, and 258 metric tons with further controls in FY 1979.

The expected cash requirement for new and existing facilities is estimated at 29.9 million dollars. Estimated investment requirement and estimated total annualized cost for the period FY 1971 through FY 1979 are $9.5 million and $3.8 million, respectively.

Industry Structure

Characteristics of the Firms. In 1973, it is estimated that there were 39 ingot manufacturers and 35 brass mills that had a casting department.

The basic raw material is copper-bearing scrap from obsolete consumer and industrial products and also home scrap in the case of brass mills. Ingot manufacturers produce ingot to 31 standard compositions for use by foundries. Brass mills produce sheet, rod, plate, and tubing from a large number of alloys. Furnace size distribution is as follows:

Size, annual metric tons		Number of Furnaces	Percent of Capacity
Ingot Producers	Brass Mills		
60-1,193		80	8
1,194-5,080		29	12
5,081-14,670		13	20
	2,849-14,243	70	60
		192	100

Current Capacity and Growth Projections. Ingot production in 1972 is estimated to be 253 thousand metric tons. No growth in capacity has taken place since 1963. The ingot industry is expected to remain stable at a level near 270 thousand annual metric tons. As the number of ingot manufacturers has decreased from 60 in 1969 to 39 in 1972, plant expansion has maintained the annual capacity approximately at a constant level.

In 1969, brass mills reached a peak production of 474 thousand metric tons of reprocessed brass and bronze scrap. It is estimated that production will be 425 thousand metric tons in 1972, and 490 thousand tons in 1979. Since 1960, growth has taken place at a rate of about 2-1/2 percent per year; this rate is expected to be maintained through 1979.

Emission Sources and Pollutants

Metallurgical fumes consisting chiefly of zinc oxide and lead oxide are the major emissions from the reverberatory and rotary furnaces that are used by ingot manufacturers and from the induction furnaces that are used by the brass mills. Fly ash, carbon, and mechanically produced dust are often present in the exhaust gases, particularly from the furnaces used by the ingot manufacturers. Zinc oxide and lead oxide condense to form a very fine fume which is quite difficult to collect.

The emission factors for particulates are 35 kg per metric ton of metal charged for a reverberatory furnace, 30 kg per metric ton for a rotary furnace, 1 kg per metric ton for an electric induction furnace,* 6 kg per metric ton for a crucible furnace, and 36.75 kg per metric ton for a cupola furnace.

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* This factor was used in this report; however, the calculated factor from data on three brass mills was 5.3, 5.7, and 8.3 kg per metric ton.

The estimated particulate emissions (in metric tons) for ingot producers and brass mills are:

Fiscal Year	Mode	Particulates Ingot Producers	Brass Mills	Total
1971	Without further control	--	--	9,740
1975	Without further control	9,320	426	9,740
1975	With further control	233	8	241
1979	Without further control	9,940	490	10,430
1979	With further control	248	10	258

Control Technology

Ingot manufacturers use fabric-filter baghouses, high-energy wet scrubbers, and electrostatic precipitators because of their high efficiency in collecting the fine zinc oxide fumes. Fifty-nine percent use a baghouse, 25 percent use a scrubber, 9 percent have no controls, and 7 percent use an electrostatic precipitator. The latter will drop to 5 percent shortly because one plant is dissatisfied with the low recovery efficiency of its electrostatic precipitator.

Brass mills use fabric-filter baghouses exclusively.

Control Costs

The costs for controlling the emission of particulates from the model furnaces representing the industry are given in Table IV-17.

TABLE IV-17. COST OF CONTROL FOR SELECTED MODEL PLANTS FOR THE SECONDARY BRASS AND BRONZE INDUSTRY

Model Size, metric tons/hour	Investment, $1,000 expected	min	max	Annualized Cost, $1,000 expected	min	max	Unit Cost $/metric ton/hour expected	min	max
68 (Ingot)	100	69	142	57	38	83	4.67	3.12	6.85
32 (Ingot)	69	48	102	30	20	44	9.18	6.17	13.49
11 (Ingot)	47	33	71	23	15	33	28.82	19.15	41.30
25 (Brass Mill)	30	22	40	5	4	7	0.80	0.59	1.06

The estimated total direct control costs for the secondary brass and bronze industry during the period FY 1971 through FY 1979 are as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	9.2	7.0	12.4
Annual Costs			
Capital Charges	1.2	.9	1.6
Operating and Maintenance	2.6	1.9	3.3
Total Annual Costs	3.8	2.9	4.9
Cash Requirements	29.4	23.2	36.8
New Facilities			
Investment	.306	.228	.415
Annual Costs			
Capital Charges	.040	.031	.052
Operating and Maintenance	.015	.011	.019
Total Annual Costs	.055	.042	.071
Cash Requirements	.460	.370	.589

An amortization period of 15 years was used for the control equipment.

Secondary Lead Industry

Introduction and Summary

Nature of Product and Process. Lead is used in storage batteries, leaded gasolines, in construction (as caulking lead, sheet lead, pipe, etc.) in bearing metals, brasses and bronze, for ammunition, cable sheathing, pigments and chemical, solders, type metals, collapsible tubes, foil, terne coatings on steel, and for weights and ballast in shipbuilding.

Only the lead used in ammunition, leaded gasolines, pigments, chemicals, and terne coatings is not recoverable. Lead is easily recovered, either as an alloy or as secondary lead. Lead and lead alloys melt at relatively low temperatures and their oxides are easily reduced. One of the major uses for lead is for grids in storage batteries. Much of this lead is recycled. Lead oxide on battery grids is reduced to lead in cupolas or blast furnaces. Other metallic lead and lead-alloy scrap is melted and refined in simple kettle or pot furnaces. Some of it is recovered by sweating, i.e., separating the lead from higher melting constituents by melting just above the melting point on a sloping hearth and collecting the molten lead run-off.

Emissions and Control Costs. Metallurgical fumes consisting of particulate emissions which are chiefly lead oxide. Total industry emission are 5600 metric tons in FY 1971 and 1480 metric tons in FY 1979 with further controls.

The expected cash requirements for new and existing facilities in the secondary lead industry is $22.1 million, with an investment requirement of $10.8 million, and a total annualized cost of $2.5 million.

Industry Structure

Characteristics of the Firms. For the purpose of this report, the secondary lead industry is defined as that industry which recovers lead or lead alloys from scrap by smelting and/or refining lead scrap. This does not include the activities of scrap dealers who may sweat lead.

A total of 22 companies was identified as participating in the secondary lead industry. These companies operate a total of 45 plants. The two leading producers are estimated to account for about 65 percent of production.

Current Capacity and Growth Projections. The secondary lead recovered from scrap in 1970 was approximately 526,000 metric tons. Industry capacity is estimated to be about 752,000 metric tons (assuming a production rate at 70 percent of capacity). In 1971, production rose to 528,000 metric tons. Future growth in the secondary lead industry is projected at 3.2 percent per year. Plant capacities were estimated on the basis of 1970 production.

Emission Sources and Pollutants

Emissions of particulates occur from lead-processing furnaces. Generally, about 2/3 or more of the output of the secondary lead industry is processed in blast furnaces or cupolas which are used to reduce the lead oxide in the form of battery plates or dross, to lead. If oxide reduction is not needed, then lead scrap can be processed in reverberatory furnaces. Kettle or pot furnaces may be used to produce small batches of alloys for holding or refining lead. These lead processing furnaces represent obvious particulate-emission sources, the primary emissions being lead oxide. Another particulate emission source is the slag tap and feeding ports on the cupolas and reverberatory furnaces. Although lead is occasionally sweated in a reverberatory furnace, reclamation of secondary lead by this means is a very small portion of total production. Emissions from slag operations are not known.

The industry estimate of 90 percent net control in 1970 indicates that nearly all plants had emissions controls of some sort. The growth in control to 98 percent net control in 1979 is estimated based on implementation of the proposed new source performance standards.

The past, current, and expected future control of particulate emissions in the secondary lead industry are estimated below:

Fiscal Year	Mode	Particulates, metric tons
1971	Without further control	5,600
1975	With further control	3,275
1979	With further control	1,480

Control Technology

Either a baghouse or a wet scrubber can be utilized to achieve control of emissions. The baghouse is chosen for this cost analysis because it is generally cheaper. It is assumed baghouse life averages 15 years.

Control Costs

The assumption of an average emission factor for cupolas and reverberatory furnaces allows the breakdown of the secondary lead industry on the basis of capacity alone. Available capacity data indicate three model plant sizes. The estimated industry capacity and model plant data are given in the tabulation below.

	Capacity Range, metric tons/day	Number of Plants	Total Capacity, metric tons/day	Model Plant Capacity, metric tons/day
Plant Model I	83-181	23	2482	109
Plant Model II	27-82	6	327	54
Plant Model III	12-26	16	253	15.8
Industry Total	12-181	45	3061	

The capital investment, annual cost, and unit cost per pound of capacity are given for each of the three model plants shown in Table IV-18. Annual costs include capital charges, operating and maintenance, and credits for by-product recovery value. Since the lead oxide collected in the control equipment is recycled into the smelting furnace, it has value as a by-product; therefore, the recovery of this lead oxide lowers estimated operating and maintenance costs.

The estimated secondary lead industry costs for the period FY 1971 to FY 1979 are:

	$ Thousands		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	8698.66	5171.81	11963.36
Annual Costs			
Capital Charges	1143.64	705.49	1563.17
Operating and Maintenance	882.13	268.39	1457.13
Cash Requirements	18614.17	10753.20	25598.48
New Facilities			
Investment	2108.15	1214.74	3091.17
Annual Costs			
Capital Charges	277.17	173.09	388.26
Operating and Maintenance	200.74	57.86	370.10
Cash Requirements	3479.15	2256.27	4905.07

TABLE IV-18. COSTS FOR CONTROL FOR SELECTED MODEL PLANTS FOR THE SECONDARY LEAD INDUSTRY

Model Size, metric tons/day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $1,000/metric ton/day		
	expected	min	max	expected	min	max	expected	min	max
109.0	305	171	434	68.9	26.3	108.1	0.63	0.24	0.99
54.0	148	79	218	34.3	11.3	54.4	0.64	0.21	0.99
15.8	59	37	82	15.3	9.3	21.7	0.97	0.59	1.37

Secondary Zinc Industry

Introduction and Summary

Nature of Product and Process. Zinc is necessary in modern living; it stands fourth among the metals of the world--being exceeded only by iron, aluminum, and copper. Zinc is utilized chiefly in automobile, household appliances, and hardware industries. The metal has three major uses (1) for zinc base alloy die castings, (2) for galvanizing steel, and (3) in the manufacture of the copper-zinc alloy, brass. Other major uses are rolled zinc for dry-cell canisters, and zinc oxide for use in rubber and paints.

Secondary zinc comes from two major sources, the zinc-base alloys and the copper base alloys. Most of the secondary zinc recovered is accounted for in reconstituted copper-base alloys: slab zinc is next, then chemical products and zinc dust.

For the purpose of this report, the secondary zinc industry is defined as that industry which uses sweating and/or distilling operations to produce zinc slab, dust, or oxide solely from scrap. It does not include the activities of:

(1) Primary zinc producers that may manufacture zinc from scrap and ore

(2) Secondary brass and bronze plants that recover zinc in copper alloys

(3) Chemical manufacturers that produce zinc compounds by chemical treatment of zinc scrap

(4) Scrap dealers that may sweat zinc.

Emissions and Control Costs. Sweating and distilling fumes consisting chiefly of zinc oxide particulates account for the major share of the emissions from secondary zinc plants.

Estimated amounts of emissions from the zinc secondary industry are 617 metric tons in FY 1971 without controls, and 145 metric tons in FY 1969 with further control.

The expected cash requirement for existing facilities is $5.45 million, with an investment requirement of $2.09 million, and an annualized cost of $0.68 million for the period FY 1971 through FY 1979.

Industry Structure

Characteristics of the Firms. It is estimated that 14 operating plants comprise the secondary zinc industry.

Current Capacity and Growth. The total secondary industry slab zinc capacity stood at 18,100 metric tons at the end of 1972. Redistilled secondary zinc slab production in 1971 was 73,400 metric tons, of that total 11,200 metric tons were produced by the secondary zinc industry, the remainder was produced by the primary industry.

Other zinc materials produced by the secondary zinc companies included zinc dust and zinc oxide. Figures are not available for total secondary zinc dust and zinc oxide capacity; estimates were derived from the available data. To further complicate capacity estimation, some production set-ups permit production of either oxide or slab.

In 1971, slightly over 24,500 metric tons of zinc in the form of zinc oxide was produced from zinc scrap. It is assumed that nearly all of this oxide is produced by the secondary zinc companies and that this production is indicative of a secondary capacity of 31,700 metric tons per year of contained zinc.

The production of zinc dust from zinc-base scrap in 1971 totaled 26,300 metric tons. It is assumed that much of this production came from the secondary industry and that secondary capacity is 31,700 metric tons per year.

On the above basis the total secondary zinc industry (as defined above) has a capacity for producing refined zinc products containing 81,700 metric tons of zinc per year.

Growth in refined secondary zinc capacity is expected to be essentially nil. Production in the three segments of the industry reviewed above stood at 63,100 metric tons in 1962, and 62,100 metric tons in 1971. Peak production occurred in 1968 and totaled 70,100 metric tons.

No data are available for sweating capacity. It is assumed that much of the feed material for production of refined secondary zinc is sweated. Sweating capacity is therefore placed at 63,500 metric tons/year. Sweating can be performed in various types of furnaces.

Emission Sources and Pollutants

There are at least four operations which generate emissions in the secondary zinc industry: materials handling, mechanical pretreatment, sweating, and distilling. This report is concerned with control costs for emissions from the sweating and distilling operations, as insufficient data are available for calculating the possible costs of controlling emissions from the other sources.

In the sweating operation, various types of zinc containing scrap are treated in either kettle or reverberatory furnaces. The emissions vary with the feed material used and the feed material varies from time to time and from plant to plant. Emissions may vary from almost none to 15 kg of particulates per ton of zinc reclaimed. For the purpose of this report, it is assumed that the maximum emission rate applies.

In the case of the various types of zinc distilling furnaces, the accepted emission rate is 23 kilograms/metric ton of zinc processed. Some distillation units produce zinc oxide and normally utilize a baghouse for collection of the product. In this study it was assumed that these baghouses are sufficient to meet national process weight standards. However, for the purpose of calculating control costs, it was assumed that essentially all of the estimated zinc oxide capacity could be switched to slab zinc or dust production, and emission controls would be required.

Controlled and uncontrolled emissions from secondary zinc sweating operations cannot be estimated with an acceptable degree of probable accuracy, as there are no reliable data available.

The estimated emissions from secondary zinc distillation based on available production estimates and an average emission factor of 23 kg per metric ton are tabulated below. It is estimated that 57 percent of the emissions were controlled in 1971 and that 90 percent will be controlled in 1979.

Fiscal Year	Mode	Particulates, metric tons
1971	Without further control	617
1975	With further control	219
1979	With further control	145

Control Technology

The major emission of concern is particulates, which consist mainly of zinc oxide. Baghouses have been shown to be effective in controlling both distillation- and sweating-furnace emissions except when the charge contains organic materials such as oils.

Control Costs

A complete accounting of secondary zinc plants by type of furnaces used and the product or products produced is not available. Based on the limited information, it is assumed that the industry's 14 plants can be represented by two models: two Model I plants each consisting of 7,260 metric tons per year sweating capacity and 10,900 metric tons per year distilling capacity, and twelve Model II plants each consisting of 4,080 tons per year of sweating capacity and 4,900 tons per year of distilling capacity.

The costs calculated for control of the model plants are given in Table IV-19. Model I plant unit costs are estimated at an average value of 0.30 cents per pound of annual capacity; while the smaller Model II plants have estimated unit costs that average 0.39 cents per pound of annual capacity.

TABLE IV-19. COSTS OF CONTROL FOR SELECTED MODEL PLANTS FOR THE SECONDARY ZINC INDUSTRY

Model Size, metric tons/ year (distilling capacity)	Investment, $1000			Annualized Cost, $1000			Unit Cost, $/metric ton/year		
	expected	min	max	expected	min	max	expected	min	max
4,990	138	80.4	195	43.2	22.5	64.4	7.85	4.09	11.7
10,900	225	131	345	72.3	38.6	113.	6.03	3.22	9.42

Estimated total direct cost of control for the secondary zinc industry during the period FY 1971 through FY 1979 are as follows:

	$ Millions Expected	Minimum	Maximum
Existing Facilities			
Investment	2.09	1.21	2.89
Annual Costs			
Capital Charges	0.27	0.19	0.37
Operating and Maintenance	0.39	0.23	0.57
Total Annual Costs	0.68	0.42	0.94
Cash Requirements	5.45	3.78	7.04
New Facilities		None planned	

BURNING AND INCINERATION GROUP

Dry Cleaning

Introduction and Summary

Nature of Product and Process. The dry-cleaning industry contributes to air pollution by the release of organic-solvent vapors to the atmosphere. The amount of solvent emitted to the atmosphere from any one dry-cleaning plant is dependent upon the equipment design solvent used, the length of certain operations in the cleaning process, the precautions used by the operating personnel, and the quantity of clothes cleaned. The most important of these items are the precautions used and the weight of the clothes cleaned.

Because of the higher capital investment required for emission controls on petroleum-solvent plants it is believed that all new plants will use synthetic solvents, and that 50 percent of the petroleum naphtha solvent plants will shut down or convert to synthetic solvent operations by 1979.

Emissions and Control Costs. Total industry emissions in fiscal year 1971 are estimated to be about 130,000 metric tons of petroleum naphtha and 53,000 metric tons of chlorinated hydrocarbons (perchlorethylene, etc.). In FY 1979, controlled emissions would be 6,800 metric tons of petroleum naphtha and 41,000 metric tons of chlorinated hydrocarbons.

Direct control costs to achieve this level of emission control will require an investment of $140 million. Annualized costs are estimated to be about $12 million because of the net savings from recovered solvents.

Industry Structure

Characteristics of the Industry. There are basically two types of dry-cleaning installations; those utilizing synthetic solvents, such as perchlorethylene, and those utilizing petroleum solvents such as Stoddard. The trend in dry-cleaning operations of today is toward smaller packaged installations located in shopping centers and suburban districts. These installations utilize synthetic solvents while the older, larger commercial plants tend to utilize petroleum solvents. It is estimated that approximately 55 percent of the dry cleaning is accomplished by synthetic solvents with the remaining 45 percent accomplished by petroleum solvents. With the small and old petroleum solvent plant being replaced by synthetic plants, it is estimated by 1979, 80 percent of the dry cleaning will be accomplished with snythetic solvents. The larger commercial plants utilizing petroleum solvents will comprise only 20 percent of the market.

Current Capacity and Growth Projection. Applying an annual growth factor of ten percent (and a cost factor of \$0.97/kg of dry cleaning) to the plant inventory of 1970 supplied by the U. S. Department of Commerce, Bureau of Census, it is estimated as of 1973 there are 31,400 dry cleaning establishments having a capacity of 2.0×10^9 kg of textiles/year. Applying this same growth factor of 1.1 through 1979, it is estimated that the capacity of the dry-cleaning industry as of 1979 will be 2.2×10^9 kg of textiles/year. The growth factor for the dry-cleaning industry is assumed to be equal to the growth in overall United States population.

Emission Sources and Pollutants

Emission factors for the dry-cleaning industry are specified by the type of solvent utilized and that are emitted directly to the atmosphere from equipment vents. Solvent losses in filter muck that could be emitted to the atmosphere have not been considered.

Synthetic Solvents. Older synthetic solvent plants using separate vessels for cleaning and drying emit about 105 kg of hydrocarbons per metric ton of textiles. Most modern synthetic solvent plants combine the cleaning, extraction, and drying operations utilizing one vessel that is equipped with a condenser for recovery of vapor solvent. Emissions from the single-vessel unit average about 47 kg per metric ton of textiles. Utilizing activated-carbon adsorption systems for further vapor recovery, the emissions are reduced to 38 kg per metric ton for the older plants, and about 25 kg per metric ton for the modern plants. These emissions can be reduced further (by 30 to 50 percent) by well-maintained equipment and good operating procedures by personnel.

Petroleum. Emissions from petroleum solvent plants can be as high as 154 kg of solvent per metric ton of textiles. Although there are adsorption units commercially available for petroleum solvent machines, to date none have been installed. It is estimated, however, that these adsorption units are capable of recovering as much as 95 percent of the evaporated petroleum solvents.

Approximately half of the synthetic plants in operation today are not utilizing activated-carbon adsorbers to reduce their emission levels. Using a reduction of emissions of 24 kg per metric ton of textiles, it is estimated installation of adsorption units in these plants would reduce the quantity of synthetic solvent vapors emitted to the atmosphere by 13,600 metric tons per year for the United States.

Although petroleum solvent adsorption systems are being developed, none of the petroleum solvents plants in operation today have these systems installed. Assuming installation of adsorption units can reduce emissions by 90 percent or 135 kg per metric ton of textiles, it is estimated that the quantity of petroleum solvents emitted to the atmosphere can be reduced by 127,000 metric tons per year for the United States.

Estimated controlled and uncontrolled emissions (in thousand metric tons) are as follows:

Fiscal Year	Mode	Hydrocarbons	Solvents
1971	Without Further Control	130	53
1975	Without Further Control	136	56
	With Further Control	14	28*
1979	Without Further Control	68**	82
	With Further Control	6.8	41

* Although carbon adsorbers are capable of reducing emissions by nearly 100 percent, in actual practice emissions are reduced by 50 to 70 percent.

** Assumes 30 percent of 1975 capacity switched to synthetic solvents and 20 percent refined by 1979.

Control Cost

Table IV-20 shows the costs of control for model size plants. Investment costs are much lower per ton of annual capacity for synthetic solvent plants, which with the credit for recovered solvent yield, an annualized credit amounting to about $3.30 per annual metric ton compared with a cost of $1.82 per ton for petroleum solvent plants.

The direct control costs for the dry cleaning industry are summarized as follows:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	140.4	117.2	166.0
Annual Costs			
Capital Charges	22.8	19.6	26.6
Operating and Maintenance	-10.2	-12.1	-8.4
Total Annual Costs	12.6	7.5	18.2
Cash Requirements	148.2	115.4	185.5
New Facilities			
Investment	3.6	3.1	4.2
Annual Costs			
Capital Charges	0.5	0.4	0.6
Operating and Maintenance	-1.0	-1.2	-0.9
Total Annual Costs	-0.5	-0.8	-0.3
Cash Requirements	1.0	0.0	2.2

Investment costs are estimated at $144 million, but annual costs would amount to about $12 million because of the credit for recovered solvents.

TABLE IV-20. COSTS OF CONTROL FOR THE MODEL PLANTS FOR DRY CLEANING INDUSTRY

Model Size, metric tons/year	Investment, $1,000			Annualized Cost, $1,000			Unit Cost. $/annual metric ton		
	expected	min	max	expected	min	max	expected	min	max
Synthetic									
46.8	1.35	1.17	1.59	-0.17	-0.28	-0.05	-3.31	-5.43	-0.94
46.8*	1.36	1.13	1.60	-0.20	-0.30	-0.09	-3.88	-5.82	-1.71
87.7	14.93	10.82	19.06	1.76	0.90	2.64	1.82	0.94	2.73

* New Facilities.

Sewage Sludge Incineration

Introduction and Summary

Nature of Process. Disposal of sewage sludge from municipal wastewater treatment by incineration generates air pollutants such as particulates and gaseous contaminants. Only particulates are considered to be emitted in concentrations high enough to warrant controls. Particulate emissions are objectionable because of their contribution to visible smoke and adverse health effects.

Emissions and Control Costs. Total particulate emissions without further control for FY 1971 are estimated to be 19.3 million metric tons. With control, particulates emissions in FY 1979 are estimated to be 6.1 million metric tons.

The estimated direct capital cost of control for the period FY 1971 through FY 1979 is $62.7 million, with corresponding estimated annualized costs of $15. million. Total cash requirements for the period are estimated to be $118.4 million.

Industry Structure

Characteristics. Incineration is one of several methods currently practiced for the disposal of sludges generated from municipal sewage-treatment plants. There are four types of sewage sludge incinerators: multiple-hearth, fluidized-bed, flash drying, and cyclonic-type.

The majority of the existing installations are of the multiple-hearth type. The size distribution of sewage sludge inceneratiors as of 1968 is:

Capacity Range, metric tons/day (dry solids)	Capacity, metric tons/day (dry solids)	Percent of Total Capacity	Number of Installations	Average Capacity, metric tons/day (dry solids)
0.27 - 9.1	270	27.13	51	5.3
9.2 - 45.3	2132	54.79	103	20.7
45.4 - 90.7	1705	14.36	27	63.4
90.8 - 272	1214	3.72	7	173.4
		100.00	188	

Capacity and Growth. Data are not available to determine current capacity but can be estimated from past growth rates and predicted future growth rates. The total number and installed capacity of sewage sludge incinerators in the United States in 1968 are estimated at 171 and 5321 metric tons/day (dry solid basis), respectively, with an annual growth rate of 14 new installations during the period 1964-1968. According to a recent EPA estimate, 70 new sewage sludge incinerators will be constructed annually in the United States during the next few years. The growth probably reflects more widespread use of incineration as an alternative to other disposal methods, such as landfills, barging to sea, and fertilizer application. Accordingly, growth rates between 1968 and 1979 were estimated as below.

Year	Number of Installations	Total Capacity, TPD (dry solids)
1968	188	5321
1969	230	6502
1970	272	7683
1971	314	8864
1972	356	10045
1973	398	11227
1974	468	13195
1975	538	15164
1976	608	17132
1977	678	19101
1978	748	21070
1979	818	23038

Emissions Sources and Pollutants

Particulate emissions from uncontrolled sewage-sludge incinerators range from 0.9 gr/dscf for multiple-hearth type and 8.0 gr/dscf for fluidized-bed type incinerators. Particulate emissions from existing facilities controlled by wet scrubbers range from 0.01 to 0.06 gr/dscf with an average value of 0.041 gr/dscf. New source performance standards proposed by EPA limit the particulate emissions at no more than 0.031 gr/dscf. Emissions factors are:

	Particulates Emissions Factor kg/metric ton (dry solids)
Uncontrolled	
Range	23 - 206
Average	115
Existing Controls (Wet Scrubbers)	
Range	0.25 - 1.6
Average	1.05
New Source Performance Standards	0.8

Control Technology

All sewage sludge incinerators in the United States are equipped with wet scrubbers of varying collection efficiencies. The low-energy scrubbers typically emit 5 to 6 times the particulates emitted from the high-energy venturi scrubbers.

The Federal Guidelines for Incinerators set the limit at 2 kg particulates/metric ton (dry solids), or 0.078 gr/dscf for sewage sludge incinerators. The well-controlled installations, therefore, are in compliance with the Federal guidelines.

Estimates of particulates emissions from sewage sludge incinerators were based on the following assumptions:

(1) Incinerator operating schedules are 3,640 hours per year for installations with capacities in the range of 0.3 to 45 metric tons per day and 8,736 hours per year for installations with capacities in the range of 45.1 to 272 metric tons per day.

(2) The majority of the existing installations are controlling particulate emissions to about 90 percent, or 1.5 kg/metric ton.

(3) To meet State Implementation Plans, existing facilities will be upgraded by 1975 to control particulate emissions to no more than 2 kg per metric ton. New facilities will be controlled to an emission level of no more than 0.8 kg per metric ton.

Based upon these assumptions, estimates of total particulate emissions (millions of metric tons) are:

Year	Mode	Particulates
1971	Without Further Control	19.3
1975	Without Further Control	24.4
	With Further Control	4.9
1979	Without Further Control	50.2
	With Further Control	6.1

Control Costs

Costs of control for the model plants are presented in Table IV-21. The total control costs for sewage sludge incineration in the period of FY 1971 - FY 1979 are:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	28.8	25.1	32.2
Annual Costs			
Capital Charges	3.79	3.55	4.08
Operating and Maintenance	2.29	1.90	2.68
Total Annual Costs	6.08	5.45	6.76
Cash Requirements	56.0	50.2	61.8
New Facilities			
Investment	33.9	29.4	38.5
Annual Costs			
Capital Charges	4.46	3.91	4.95
Operating and Maintenance	4.95	4.33	5.64
Total Annual Costs	9.41	8.24	10.59
Cash Requirements	62.4	56.2	69.5

TABLE IV-21. COSTS OF CONTROL FOR THE MODEL PLANTS (SEWAGE SLUDGE INCINERATION)

Model Size, metric tons/day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/metric ton/day		
	expected	min	max	expected	min	max	expected	min	max
Existing Facilities									
5.3	46	38	54	8.5	6.8	10.3	1.60	1.45	1.94
20.7	72	56	89	14.9	11.3	18.5	0.72	0.55	0.89
63.4	106	88	130	24.2	19.0	30.2	0.38	0.30	0.48
173	150	123	173	37.8	29.1	45.2	0.22	0.17	0.26
New Facilities									
5.3	50	41	60	12.1	9.4	14.9	2.28	1.77	2.81
20.7	79	66	92	21.7	16.9	26.5	1.05	0.82	1.28
63.4	118	96	138	35.4	27.1	44.2	0.56	0.43	0.70
173	168	139	198	56.6	43.5	70.1	0.33	0.25	0.41

Solid Waste Disposal

Introduction and Summary

Nature of the Process. Disposal of solid wastes contributes to air pollution from incineration and open burning of solid wastes. Air pollutants emitted to the atmosphere from such practices include particulates, carbon monoxide, sulfur oxides, nitrogen oxides, fluorocarbons, hydrochloric acid, and odors. The levels of these pollutants emitted are primarily dependent on the input or the material being burned; for incinerators, levels are also dependent on the specific incinerator design and upon the specific methods of operation. Particulates are emitted in the highest concentrations, and are the specific pollutant subject to controls. There are no current regulations for odors, hydrochloric acid, and fluorocarbons.

Emissions and Control Costs. Total particulate emissions from solid waste disposal by burning processes in FY 1971 (without further controls) are estimated to be 6.5 million metric tons. In FY 1979, controlled particulate emissions are estimated to be 0.14 million metric tons.

The estimated direct investment cost to achieve this level of control in FY 1979 is estimated to be $1.64 billion. The estimated annualized cost associated with this investment is estimated to be $694 million. Cash requirements over the period FY 1971 - FY 1979 are estimated to be $4.80 billion.

Industry Structure

Characteristics. The solid waste disposal methods practices in FY 1971 are as follows:

Disposal Method	Percent of Total Solid Waste Disposed by Method
Municipal Incinerators	5.3
Conical Burners	6.1
On-Site Incineration	8.3
On-Site Open Burning	8.3
Open Dumps (burned)	13.9
Open Dumps (unburned)	30.6
Sanitary Landfills	11.1
Miscellaneous Other (unburned)	16.4
Total	100.0

Of these, the primary methods of solid disposal used in the future are judged to be municipal incinerators and sanitary landfills.

Of the two types of municipal incinerators, the refractory-lined furnace type is the more common type in the U. S.; the water-wall or waste-heat recovery type is more common in Europe. The water-wall units offer the advantage of steam generation, and (as a consequence) of heat recovery in steam generation, flue-gas temperatures are lower than refractory-lined units. Incinerators with lower gas temperatures have smaller volumes of flue gases to control, and so require less costly control equipment. In addition, with the low temperatures from heat recovery, incinerators can utilize control equipment that would not survive the high temperature flue gases from refractory-lined furnaces unless these flue gases are cooled prior to the control system.

Current Capacity and Growth Projections. The current generation rate and projected growth of solid wastes in the United States is based upon: (1) generation of 4.6 kg per day per capita in 1967, (2) a 3 percent yearly increase in the per capita generation rate, and (3) a population growth of 1.1 percent per year. Accordingly, solid waste generated in 1973 is estimated to be 426 million metric tons. Because open burning is outlawed and there is no anticipated growth of on-site incineration (because of the relatively high cost of control equipment), an increasingly proportion of solid wastes will be disposed of by municipal incineration and in sanitary landfills.

In 1966, the 250 municipal-size incinerators in operation in the United States had an average capacity of 272 metric tons per day. Approximately 70 percent of these were installed prior to 1960, and so were not designed to minimize air pollution. Because of the increased emphasis on control of air pollution after 1966, relatively few new incinerators were built. Several municipalities ceased operations of their incinerators.

Based on existing data, it was estimated that in 1973 there were 300 operating incinerators having a total capacity of 81,600 metric tons per day. This capacity will have to be increased to handle the estimated 3 percent yearly increase in the per capita generation rate as well as to handle about 10 percent of the solid wastes that were previously disposed of by open burning. This requires the building of new incinerators with a total additional capacity of 9,100 metric tons per day.

Although not actually a control technology, sanitary landfill is an alternative for solid waste disposal. It is estimated that in 1973 approximately 23 million metric tons per year of solid wastes will be disposed in sanitary landfill operations. This capacity will have to be increased to handle the 3 percent yearly increase in the per capita operation rate and to handle about 90 percent of the solid wastes that were previously disposed of by open burning. This requires an increase in capacity of about 27 million metric tons per year through 1975. This demand rate will decrease to about 6.4 million metric tons per year from 1975 through 1979.

Emission Sources and Pollutants

Emissions of particulates and other air pollutants from solid waste disposed by open burning, on-site incineration, and municipal incineration are tabulated below.

Pollutant	Open Burning Emission Factor, kg/metric ton wastes
Particulates	8
Carbon monoxide	43
Sulfur oxides	0.5
Nitrogen oxides	3
Hydrocarbons	15

The controlled and uncontrolled particulate emissions from open burning, on-site incineration, and municipal incineration are summarized below (millions of metric tons per year).

Year	Mode	Particulates
1971	Without Further Control	6.5
1975	Without Further Control	1.3
	With Further Control	.12
1979	Without Further Control	1.8
	With Further Control	0.14

Control Technology

Because no control technology is applicable to open burning, suitable alternatives for emissions control are municipal incinerators and sanitary landfill. To control particulate levels from municipal incinerators to within Federal regulations, either high-efficiency wet-scrubber or electrostatic precipitator will have to be utilized.

Control Costs

Model plant costs associated with the disposal of solid waste are summarized in Table IV-22. Only the costs for particulate control are included for on-site and municipal incinerators and not the actual cost of the incinerator itself.

The direct control costs for solid waste disposal in the period FY 1971 - FY 1979 are:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	1185	1094	1391
Annual Costs			
Capital Charges	146	135	158
Operating and Maintenance	358	313	400
Total Annual Costs	504	448	558
Cash Requirements	3741	3437	4044
New Facilities			
Investment	453	421	489
Annual Costs			
Capital Charges	57	53	62
Operating and Maintenance	132	118	146
Total Annual Costs	190	171	208
Cash Requirements	1061	1000	1131

TABLE IV-22. COSTS OF CONTROL FOR SELECTED SOLID WASTE DISPOSAL MODELS

Model Size, metric tons/day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/metric ton/day		
	expected	min	max	expected	min	max	expected	min	max
Landfills (close-in)									
91	301	256	357	108	81	134	3.96	2.98	4.94
815	2360	1970	2680	825	628	1010	3.37	2.57	4.13
1360	3740	3020	4320	1320	988	1630	3.23	2.43	3.99
Landfills (remote)									
91	336	283	395	229	175	280	8.42	6.42	10.27
815	2580	2120	2990	1790	1330	2230	7.29	5.43	9.09
1360	4160	3550	4770	2870	2140	3550	7.03	5.24	8.70
Municipal Incinerators (Wet Scrubber Control)									
270	530	368	723	244	161	325	3.58	2.37	4.77
270*	495	393	603	242	180	308	3.56	2.65	4.53
Municipal Incinerators (Electrostatic Precipitator Control)									
270	400	266	526	118	80	156	1.73	1.18	2.29
270*	392	266	516	111	82	156	1.63	1.20	2.29

* New Facilities.

Teepee Incinerators

Introduction and Summary

Wood wastes accumulated in the manufacture of forest products are usually disposed of by incineration. Because of the fire hazards in open burning, methods were developed to contain the sparks. Teepee incinerators, also known as conical or wigwam burners, are the method usually employed. A large majority of teepees are located in Western States. Others are scattered throughout the country, but principally in Texas, Louisiana, Arkansas, Kentucky, Georgia, and North Carolina.

Nature of the Product and Process. Typical wood wastes from sawmill operations are slabs, edgings, lumber trim, sawdust, shavings, and bark. In plywood manufacture, the wastes include log trim, green veneer clippings, trim, dry veneer trim, panel trim, and sander dust. Moisture content of these wastes may vary from 2 percent to as high as 70 percent.

Two types of waste feed systems are used in teepee incinerators. In one, the wastes are air-lifted through a cyclone into a surge bin, discharged at a controlled rate through a variable-speed screw feeder to a conveyor, and dropped into the burner. The other system is used for wastes with high moisture content in which the waste is predried in a rotary dryer using flue gases from the burner.

Emissions and Control Costs. The total number of active teepee incinerators in 1973 is estimated at 835. Of these, 41 percent are assumed to be modified in some form. By 1979, it is projected that the total number will decline to about 490, all of which will be modified to meet state air-pollution-control regulations. Capacities of teepee incinerators are expected to decline from 10.6 million metric tons of wood wastes, containing 50 percent moisture, in 1973, to 6.3 million metric tons in 1979.

Nationwide emissions of particulates, carbon monoxide, and hydrocarbons from teepee incinerators in FY 1971, FY 1975, and FY 1979, with and without additional controls are estimated as follows:

	Thousands of metric tons/year		
	FY 1971	FY 1979	
	Without Further Controls	Without Further Controls	With Further Controls
Particulates	130	50	13
Carbon Monoxide	487	188	63
Hydrocarbons	36	14	1.5

Capital costs for installation of emission controls on teepee incinerators have been estimated to range from $20,000 to $45,000 per unit depending on diameter of the teepee base. Assuming an average diameter of 18 meters, capital costs for 490 teepee incinerators would be about $15 million. Annual costs for operations and maintenance have not been calculated.

Industry Structure

Characteristics of the Firms. In 1967, more than 10,000 sawmills and planing mill companies and about 500 veneer and plywood companies were reported by the U. S. Bureau of the Census as operating one or more establishments. Industry concentration is relatively low in the lumber industry with the top 10 producers accounting for about 20 percent of the total; while the top four producers account for about one-third of the plywood output. Leading producers are multi-product companies with mills in the principal producing regions in the United States. Capital requirements for entry into the field are relatively low; availability and cost of timber being far more important determinants.

Current Capacity and Growth Projections. Nationwide statistics on teepee incinerators are not available. In 1973, the total number of active teepee incinerators in five states (California, Georgia, Louisiana, Oregon, and Washington) was estimated at 557, of which 227 have been modified in some form. Assuming that two-thirds of the incinerators are located in these states, total number of active teepees in the United States is estimated at 835. Based on the size distribution of the modified teepees in Oregon, the total number of teepees by size would be as follows:

Design Capacity, metric tons/hour	Number of Teepees in 1973
0.0 - 1.8	157
1.8 - 3.6	400
3.7 - 5.4	191
5.4	87
	835

Based on an average operating schedule of 4,000 hours per year and an average burning rate of 3.2 metric tons per hour, annual disposal of wood wastes by teepee incinerators could be 10.6 million metric tons.

The number of teepee incinerators is expected to decrease to an estimated 490 by 1978, all of which will be modified to meet state air-pollution regulations. Assuming the same size distribution of teepees, annual incineration of wood wastes would be 6.3 million metric tons.

Emission Sources and Pollutants

A teepee incinerator is a conical-shaped steel shell, with approximately the same based diameter and height, topped with a dome-shaped spark-arrestor screen. Wood wastes are dropped on a burning pile from a conveyor at the side of the shell. Combustion air is provided by natural draft or fans. Air pollutants are contained in the flue gases exiting through the dome. Principal contaminants are smoke and ash particulates, carbon monoxide, and hydrocarbons.

Control Technology

Two approaches have been used for reducing emissions from teepee incinerators: modification of teepees and the use of gas-cleaning equipment. In the latter approach, wet scrubbers and afterburners have been used. The use of gas-cleaning equipment has been found expensive and also ineffective in eliminating smoke. The preferred approach to emission control is through improved combustion by modification of teepee construction and operation.

Four methods of teepee modification are in general use. The first is the Oregon State University modification used on most of the modified teepees in Oregon.

A second method has been developed for use in planing mills or plants producing relatively fine, dry wastes. In this method a refractory ring, about 1.5 to 1.8 meters high and from 1/4 to 1/2 the teepee diameter, is erected in the center of the teepee. This surmounts a grate or manifold system supplying underfire combustion air from external blowers. Overfire air is supplied in a tangential entry either at the refractory ring or at the shell of the teepee. In some of these installations the wood waste is fed into the refractory ring by gravity from a cyclone. In others the feed is blown into the ring tangentially by an external blower. This system can operate with essentially no visible emissions.

A third method is being used on one teepee in California handling redwood mill wastes, including wet bark. The unit has been completely lined with refractory. Both underfire and overfire air is supplied by blowers. This teepee generally operates with no visible emissions. However, excessive emissions have been reported during startup on some occasions.

A fourth method, used on the majority of the modified teepees in California, employs a recirculating air arrangement, in which part of the exhaust gas is collected in a dished baffle inside the top of the teepee. The exhaust gas is drawn through external pipes to one or more blowers which reinject the recycled gas into the teepee as overfire air. Exhaust from the teepee is through the annulus around the baffle. The temperature of the exhaust is controlled by thermocouple-activated dampers in the recirculation ducts. Balancing underfire air, recirculating air, and the exhaust with the waste feed are important for efficient use of this system.

Emission Sources and Pollutants

Controlled versus uncontrolled emissions for FY 1971, 1975, and 1979 are shown below.

Year	Mode	Thousand of metric tons/year		
		Particulates	CO	Hydrocarbon
1971	Without Further Control	130	487	36
1975	Without Further Control	66	248	19
	With Further Control	29	122	6
1979	Without Further Control	50	188	14
	With Further Control	13	63	1.5

These estimates for FY 1971 and 1975 are interpolations from estimated numbers of teepee incinerators and annual disposal rate of wood wastes for 1968, 1973, and 1978 as follows:

Year	Number of Teepee Incinerators	Yearly metric tons disposal rate, 10^6
1968	3330	42.4
1971	1275	16.2
1973	835	10.6
1975	650	8.3
1978	490	6.3
1979	490	6.3

It is also assumed that 490 teepee incinerators will have installed some form of controls by FY 1975 meeting air-quality regulations.

Control Costs

Capital costs of the Oregon State University (OSU) modification during the 1970-1972 period were obtained from five mills in Oregon as follows:

Teepee Base, Diam., meters	Capital Costs of Controls, dollars
17	20,000
18	30,000
18	30,000
21	34,000
21	45,000

Capital costs of controls achieved through other methods of teepee modification were provided by the State of California as follows:

Teepee Modification	Teepee Base Diam., meters	Capital Costs of Controls, dollars
Refractory ring	15	5,000 to 15,000
Refractory lining	17	Too costly for avg. mill
Exhaust gas recirculation	12-24	20,000 - 80,000.

The cost of teepee modification required for emission control is substantial. The cost of Oregon State University modification is one or two times the cost of the teepee itself. The high cost of controls will probably force small mills to abandon the use of existing teepees and look for alternative means of waste disposal.

Assuming an average diameter of 18 meters, capital cost for modification of 490 teepee incinerators would be about $15 million. Annual costs for operations and maintenance have not been calculated.

Uncontrolled Burning: Agricultural

Although modern tillage and fertilization practices have eliminated many sources of agricultural burning, there remain, however, some agricultural pursuits wherein the return of organic wastes to the soil is not practicable under existing conditions. Under these conditions, open burning of agricultural wastes is still practiced.

Examples of agricultural burning used to facilitate crop harvesting include burning of potato vines, peanut vines, and sugar cane. Other instances of open agricultural burning include grass fields in the Williamette Valley of Oregon, rice land in California, orchard tree wastes, marshlands in Texas and Louisiana which serve as "range" for muskrats, incineration of cotton gin wastes, the use of orchard heaters to prevent frost damage to fruit and fruit trees, burning of corncobs in major corn producing areas, and burning of fence rows and brush from wooded and rangeland areas.

One source has reported that, in 1970, crop residues on 453,000 hectares equivalent to 3,289,000 metric tons of residue were burned in the United States as a means of reducing losses caused by plant diseases and other soil-borne pests, and also as a means of disposing of crop residues.

Estimated emissions from agricultural burning in 1970 and 1973 indicate that 2.2 million metric tons of particulates, 12.5 million metric tons of carbon monoxide, 2.5 million metric tons of hydrocarbons, and 0.27 million metric tons of nitrogen oxides were emitted from all sources classified under agricultural burning. Particulate and carbon monoxide emissions from agricultural burning accounted for 9.2 and 9.3 percent, respectively, of total emissions of these types from all sources. Hydrocarbons and nitrogen oxide emissions from agricultural burning were 8.0 and 1.3 percent of total emissions from all sources. Emissions of sulfur oxides from agricultural burning are believed to be less than 0.1 million metric ton.

Agricultural wastes from orchards, grain fields, and range lands are burned in many states as the most practical means of ridding the land of these wastes. In order to determine the relative contribution of the burning of such material to photochemical air pollution, California researchers measured the effluent from known weights of range brush (both dry and green), barley and rice stubble, and prunings from various fruit and nut trees. The effluents were monitored in a special tower which provided an open-burning situation. Analyses were made for total hydrocarbon, expressed as HC and for carbon monoxide and carbon dioxide. Results of these experiments are shown in Table IV-23.

TABLE IV-23. YIELD OF HYDROCARBON, CO, AND CO_2 IN KILOGRAMS PER METRIC TON OF WASTE MATERIAL FROM THE BURNING OF VARIOUS AGRICULTURAL WASTES COLLECTED IN THE SAN JOAQUIN VALLEY AND SAN FRANCISCO BAY AREA OF CALIFORNIA

Waste Material	Percent Moisture	Total Hydrocarbon HC	CO	CO_2
		-- San Joaquin Valley		
Rice straw	--	4.5 ± 1.2	37 ± 9	1046 ± 153
Barley straw	--	7.3 ± 1.8	44 ± 12	854 ± 195
Native brush				
Dry	--	2.4 ± 1.3	35 ± 4	1367 ± 205
Dry and green	--	7.6 ± 2.2	41 ± 3	995 ± 119
Green	--	13.7 ± 4.4	67 ± 21	764 ± 232
Cotton	20 ± 7	1.6	37	1266
		Bay Area -- 1965		
Fruit prunings	6 ± 2	2.1 ± 0.7	23 ± 7	1120 ± 119
Native brush	2.5 ± 0.5	2.4 ± 1.1	33 ± 15	1310 ± 102
Fir chips	2.5	1.4	18	761
Redwood chips	--	1.1	35	1871
		Bay Area -- 1966		
Fruit prunings	18 ± 8	4.9 ± 2.1	33 ± 11	998 ± 179
Native brush	7 ± 4	2.2 ± 1.2	28 ± 10	1187 ± 102

Source: "Contribution of Agricultural Wastes to Photochemical Air Pollution", Journal of The Air Pollution Control Administration, December, 1966, p. 687.

(a) Figures are given with standard deviations. Entries without deviations represent one or two fires only.

Sugar Cane Burning

Before sugar cane is mechanically harvested, much unwanted foliage remains on the plants. Therefore, it is standard practice to burn the cane before harvesting to remove the greater part of the foliage. Emission factors for open-field burning of sugar cane are shown below.

	Emissions, kilograms/hectare
Particulates	250
Carbon monoxide	1700
Hydrocarbons	340
Nitrogen oxides	34

Based on these emission factors, total emissions from sugar burning based upon acreage harvested in 1972 are presented in Table VI-24.

It appears that there is no feasible alternative to open-field sugar cane burning at this time. In the absence of known control techniques for emissions (other than legislation banning the practice) there are no data on control costs.

Orchard Heaters

Orchard heaters are commonly used in various areas of the United States to prevent frost damage to fruit and fruit trees. There are five common types of orchard heaters -- pipeline, lazy flame, return stack, cone, and solid fuel. The pipeline heater system is operated from a central control and fuel is distributed by a piping system from a centrally located tank. Lazy flame, return stack, and cone heaters contain integral fuel reservoirs, but can be converted to a pipeline system. Solid-fuel heaters usually consist only of solid briquettes, which are placed on the ground and ignited.

The ambient temperature at which orchard heaters are required is determined primarily by the type of fruit and stage of maturity, by the day-time temperatures, and by the moisture content of the soil and air.

TABLE IV-24. ESTIMATED EMISSIONS FROM SUGAR-CANE BURNING, 1972

State	Land Area Harvested 1000 Hectares	Emissions[a], 1000 metric tons			
		Particulates	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
Florida	98.6	24.9	165.7	33.1	3.4
Louisiana	30.4	32.8	219.1	43.8	4.4
Hawaii	44.1	11.2	74.2	14.9	1.5
United States	273.1	68.9	459.0	91.8	9.3

Source: Calculated on basis of data in Crop Production, 1972 Annual Summary, and Compilation of Air Pollutant Emission Factors, 2nd edition, AP-42, April, 1973, p 6.12-1.

(a) Assumes that all land area is burned before harvest.

Proper location of the heaters is essential to the uniformity of the radiant heat distributed among the trees. Heaters are usually located in the center space between four trees and are staggered from one row to the next. Extra heaters are used on the borders of the orchard.

Emissions from orchard heaters are dependent on the fuel usage rate and the type of heater. Pipeline heaters have the lowest particulate emission rates of all orchard heaters. Hydrocarbon emissions are negligible in the pipeline heaters and in lazy flame, return stack, and cone heaters that have been converted to a pipeline system. Nearly all of the hydrocarbon losses are evaporative losses from fuel contained in the heater reservoir. Because of the low burning temperatures used, nitrogen oxide emissions are negligible.

There are no reported data on the total number of orchard heaters of various types in operation, nor are data available on the total number hours of operation by these heaters. Therefore, it is not possible to calculate total emissions from these sources.

Grassland Burning

Open-field burning is the least-cost means to dispose of harvest residue and provide essential thermal treatment to destroy disease organisms. One region of the United States where open-field burning is a widely adopted agricultural practice is the Williamette Valley of Oregon. In 1969, an estimated 91,000 hectares of grasslands and some 34-36,000 hectares of cereal grains residue were estimated to have been burned in the Williamette Valley. The burn removed an estimated 0.91 million metric tons of residue during the post-harvest season in August and September.

Grassland and cereal-grain residue burning is not limited to the Williamette Valley. More than 162,000 hectares of rice and other cereal grain straws are burned annually in California. Some 2,300 hectares acres of bermuda grass in Arizona, some bluegrass in Minnestoa, and various types of grasses in eastern Washington and Oregon and northern Idaho are field burned. Research has indicated that open-field burning of crop residue after harvest is an effective and economic means for destroying the seed-infecting fungus that winters in crop residues and at the soil surface.

Grassland burning in the Williamette Valley annually created serious air pollution problems, causing the practice to come under increasing public scrutiny, particularly in the metropolitan centers such as Eugene and Springfield. As a result, a ban on open-field burning has been enacted by the state of Oregon, effective January 1, 1975. This law could force major adjustments upon Oregon's grass-seed industry.

One alternative to open-field burning of grasslands is the use of mobile field sanitizers. Commercial development of mobile field sanitizers appears to be technically feasible, but their use is expected to increase grass-seed production costs significantly. Other technically feasible alternatives to open-field burning include alternative land use, soil incorporation of residues, and mechanical removal of residue followed by field sanitation. A summary of increases in total costs per hectare over open-field burning with alternative residue removal techniques is shown in Table IV-25.

Mobile field sanitizers (burners) have been tested in Oregon for the past several years, but no models are commercially produced. Data from test runs made in 1971 are shown in Table IV-26. These experiments provided, among other things, data on emissions of gases and particulate materials.

If other states follow Oregon's lead in banning open-field burning, the problem of air pollution from this source will obviously be eliminated. However, the economic consequences of such action in terms of potentially reduced product supplies and higher prices must also be considered before such legislation is enacted.

TABLE IV-25. A SUMMARY OF INCREASES IN TOTAL COSTS PER ACRE OVER OPEN-FIELD BURNING WITH ALTERNATIVE RESIDUE-REMOVAL TECHNIQUES
(Dollars per hectare)

Residue Removal Techniques	Annual Ryegrass	Perennial Ryegrass	Highland Bentgrass	Fine Fescue	Merion Bluegrass
Incorporation of residues into the soil	\$52-\$64	--	--	--	--
Mobile field sanitizer	\$12-\$25	\$12-\$25	\$12-\$25	\$12-\$25	\$12-\$25
Mechanical removal of residues followed by field sanitation(a)					
Bunching and field bucking	\$30-\$40	\$27-\$35	\$25-\$30	\$25-\$30	\$22-\$27
Stack former and mover	\$37-\$62	\$32-\$52	\$27-\$42	\$27-\$42	\$27-\$37
Chopper-blower and hauling(b)	\$106	\$84	\$62	\$62	\$54
Baling and hauling(c)	\$59-\$96	\$94-\$69	\$44-\$69	\$44-\$69	\$40-\$59
Field cubing and hauling(d)	\$84-\$168	\$84-\$128	\$62-\$91	\$62-\$91	\$54-\$77

Source: "Farmer Alternatives to Open Field Burning: An Economic Appraisal", Special Report 336, Agricultural Experiment Station, Oregon State University, October, 1971, p. 13.

(a) Costs include an \$20/hectare charge for use of a mobile field sanitizer but exclude any expenses which may be required for residue utilization or disposal.

(b) Due to a lack of data, no ranges in costs were calculated. Only custom rates of \$11/metric ton for chopping, blowing, and hauling, and \$20/hectare for field sanitation were used.

(c) Projecting a range in baling and hauling costs of \$6.60 to \$13.20/metric ton with no swathing required.

(d) Projecting a range in cubing and hauling costs of \$11 to \$19/metric ton.

TABLE IV-26. EMISSIONS DATA FROM TESTING OF A MOBILE FIELD SANITIZER FOR BURNING STRAW AND GRASS RESIDUES, OREGON WILLAMETTE VALLEY, 1971

Date 1971	Type of material	Rate		Average Smoke Density, Percent	Equiv. Ringleman number	Particulate, grains/ft^3 at 12 percent CO_2				Stack Temp., F.
		Hectare/ hr	Metric Ton/Hr			By P.H.S. wet train (D.E.Q.)	By High-Vol. Sampler Average	By Anderson Stack Sampler		
								Total	Smaller than 10 Microns	
8-19	Orchard grass	0.66	6.7	20	1	3.12	1.07	-	-	1100
8-27	Annual Rye	1.0	9.1	15	3/4	-	1.74	-	0.14	1100
9-07	Annual Rye	0.65	5.4	15	3/4	1.04	0.244	0.583	0.06	1500
9-08	Annual Rye	0.81	8.6	10	1/2	0.69	0.24	0.60	0.07	1200
9-09	Wheat stubble	1.2	--	-	-	1.48	0.526	0.82	0.02	1000
9-15	Bluegrass	0.65	--	10	1/2	-	-	0.20	0.04	1000
10-20	Rice straw	0.81	--	10	1/2	-	-	0.985	0.088	1200
11-09	Rice straw	0.61	--	10	1/2	-	-	0.66	0.160	1000

Source: "Report on Development and Testing of a Mobile Field Sanitizer", D. E. Kirk and R. W. Bonlie Agricultural Engineering Department, Agricultural Experiment Station, Oregon State University, May, 1973, p. 8.

Uncontrolled Burning: Forest Fires

General Information

Forest fires may be classified into two categories--(1) uncontrolled "wildfires" that may be caused by lightning or by negligent or accidental acts of man, and (2) "prescribed burning" of forested areas which are fires set (by man) with certain definite objectives, and which do minimum damage to the surrounding forest and the general environment. Estimated combined emissions from fires of both types are:

	Millions of Metric Tons				
Year	Particulates	SO_x	CO	Hydrocarbons	NO_x
1971-1973	1.3	neg.	3.6	0.27	0.18

These data indicate that forest-fire emissions are significant mainly in terms of particulates and carbon monoxide. Emissions of hydrocarbons and nitrogen oxides are relatively minor, while sulfur oxide emissions from forest fires are negligible.

A detailed research study pertaining to forest fire emissions was completed in mid-1973 by Illinois Institute of Technology Research Institute (IITRI). This study, conducted for EPA, was in draft form at the time of this review and no data from the draft were available. It was indicated, however, that few emissions have been measured from "actual" wildfires. Almost all emissions data have been conducted under controlled or laboratory conditions.

Recent data from laboratory burning studies conducted under the U.S. Forest Service Smoke Management Research and Development program are summarized below.

Burning Conditions	Estimated Effluent Quantities Kilogram per Metric Ton of Fuel Consumed
Live, green vegetation burned with no wind produces	50 particulate 38 hydrocarbons 75 carbon monoxide
Live, dry vegetation (exposed to heat of open flames) burned with no wind produces	15 particulate 8 hydrocarbons 23 carbon monoxide
Dead, dry vegetation burned with a head fire produces	22 particulate 14 hydrocarbons 104 carbon monoxide
Dead, dry vegetation burned with a backfire produces	9 particulate 97 carbon monoxide

These data show the amount of effluents produced under various burning circumstances.

Wildfires

Although there have been no data collected on emissions from wildfires (since the major concern in the event of wildfire occurrence is extinguishing the fire), data are available on number of fires and total acreage burned. These data are shown below. From 1966 through 1970, the average annual number of wildfires totaled 119,931, with an average of slightly over 1.8 million hectares being burned. However, it is obvious that averages in this instance can be very misleading, since in 1968 some 117,000 wildfires burned 1.1 million hectares, while in 1969 only 113,351 wildfires burned over 2.3 million hectares. Ordinarily, a small number of big fires account for a high percentage of land area burned.

	Number of Fires	Hectares Burned
1970	121,780	1,328,000
1969	113,351	2,709,000
1968	117,000	1,149,000
1967	125,025	1,886,000
1966	122,500	1,852,000
Annual Average	119,131	1,782,000

Even though there have been significant advances since World War II in fire-prevention technology and control, losses from wildfires remain large. The principal reasons for this are: increases in population, more leisure time and use of forests for recreation, greater volume of fuels, and more industrial activity in the forested areas.

Prescribed Burning

Prescribed burning is carried out only under conditions of fuel moisture, weather, and fuel arrangement that will achieve a major objective of the burn, and do minimum damage to the surrounding forest and the general environment.

In the South, prescribed burning is intended to reduce the fuel supply on the floor of the pine forests by burning such cover as saw palmetto, dry grass, ty-ty, gallberry, and smaller pine reproduction in order to create areas of low fuel to prevent crown fires, and into which a crown fire can be headed and brought to earth where it can be controlled.

In the West, a different method is dictated by rugged terrain, prevalence of fires started by lightning, and the nature of the forest. The West is still largely in the process of converting virgin stands to managed forests--a task already completed in the South. In much of the West, production of the most important species calls for clear areas in which the seedlings can get full light. Thus, clear cutting in small blocks has become general practice. This generates, in old-growth and also second-growth country, huge amounts of residue on the cut areas: cull logs, limbs, tops, foliage, and brush.

In the past, most Western states required the lowering of fire hazards by removal of the slash or burning it. In recent years, greater utilization has resulted in more of the tree being brought out of the woods for conversion to products. However, it still is not economically possible to make full use of the tree. At the present time, there is no alternative to burning much of the slash and the fuel produced in the woods.

Land Area Burned. Reasonably good records are maintained of the hectares burned by wildfires, but the same information is not readily available for prescribed burns. Also, the rate of burning differs for wildfires and prescribed fires, and the amount of fuel consumed per hectare varies with the fuel type, availability, and moisture content.

Although yearly records have not been kept, a 1964 survey of prescribed burning in the South indicated that about 0.91 million hectares were being burned annually, mostly for hazard reduction. At that time, six states were burning over 40,500 hectares--Georgia leading all states with over 324,000 hectares. In a 1970 survey, it was found that roughly 1.0 million hectares were being burned and that the burning trend was down for some states and up sharply for others. Most of the 1.0 million hectares burned in 1970 was believed to be on the 23 million hectares owned and managed by private industry. There are no data reported on the land area of prescribed burning in the western United States.

Effects on Air Quality. Less fuel is consumed by prescribed fire than by wildfires, resulting in less pollutant material released. Backing fires (most prevalent prescribed burning technique) produce about 35 percent less particulate matter than do head fires with less complete combustion.

In an 8-county area in south Georgia, particulate matter was sampled during the annual prescribed burning season. Even on the days of highest prescribed burning activity, the total amount of particulate matter in the atmosphere was well below the maximum limit of 80 micrograms per cubic meter of air established for cities by the Department of Health, Education, and Welfare.

The production of smoke from prescribed burns can be both aggrevating and dangerous when encountered on expressways and other travel lanes. Occasionally, the aftermath of a supposedly successful prescription fire can be chaotic when residual smoke mixes with early morning fog. However, there is no evidence to indicate that over the long term, air quality has deteriorated more in areas where prescribed fire is used extensively than in areas where fire is rarely used.

It has been suggested that prescribed burning may actually reduce the adverse environmental effects of wildfires by reducing their number, size, and intensity. Evidence indicates that a suspension of prescription burning might result in a six-fold increase in the land area ravaged by wildfires in the South each year. Because the per-hectare fuel consumption by wildfires is considerably more than that for prescribed fires and because the particulate count per ton of fuel consumed is also much higher, the total particulate production might be about 7 times greater without prescribed burning than with it (Table IV-27).

TABLE IV-27. ANNUAL PARTICULATE PRODUCTION FROM FOREST FIRES IN THE SOUTH

	Without Prescription Burning	At Present Level	With Increased Prescription Burning
	Prescribed Fires		
Hectares Burned, Millions	0	0.91	2.03
Fuel Consumed, Metric tons/hectare	0	6.7	6.7
Measured Particulate Produced Kilograms/metric ton of fuel	0 0	8.5	8.5
Total, million metric tons	0	0.052	0.116
	Wildfires		
Hectares Burned, Millions	5.87(a)	0.96	0.41(b)
Fuel Consumed, Metric tons/hectare	21.2	16.8	13.4
Measured Particulate Produced Kilograms/metric ton of fuel	29.0	29.0	29.0
Total, million metric tons	3.438	0.467	0.158
Total Particulate Production, million metric tons (Prescribed fires and wildfires)	3.438	0.519	0.274

(a) Predicted wildfire loss, study reported in J. Forest., Vol. 61, No. 12, Dec. 1963.

(b) Probable minimum level to which wildfires can be reduced.

Costs of Prescribed Burning. Average costs of prescribed burning in the South are reported to be less than $2.46 per hectare, although specific instances of costs as high as $12.00 per hectare have been noted. Other fuel-removal and site preparation treatments may cost from $62-$124 per acre. Technology exists for utilizing timber harvest residues, but the costs of collection, transportation, and processing are high. At this time, the most practical treatment is still prescribed burning.

Uncontrolled Burning: Structural Fires

Structural fires contribute to air pollution by a release of pollutants to the atmosphere that include particulates, sulfur oxides, hydrocarbons, nitrogen oxides, and carbon monoxide. It is estimated that approximately one million buildings annually are attacked by fire that cause 20 to 30 percent damage. From published emission factors and estimates that each building structure contains about 15 metric tons of combustiles, emission levels are estimated as shown below.

Pollutant	Emission Factor, kg/metric ton burned	Emission Levels, 10^6 kg/yr
Particulates	8.5	38.6
Sulfur oxides	0.075	0.34
Hydrocarbons	10	45.5
Nitrogen oxides	1	4.55
Carbon monoxide	32.5	148

Emissions from structural fires are assumed to be proportional to population and, accordingly, a growth factor of 1.1 percent per year is assumed. There are no applicable control technologies for structural fires other than prevention.

Uncontrolled Burning: Coal Refuse

Introduction and Summary

Before coal mines were mechanized, only the thicker and better seams of coal were developed on a large scale. The coal was mined, picked, and loaded by hand. With few exceptions only marketable coal was transported to the surface. With new and improved mining equipment, coal seams with an increasing percentage of impurities could be mined, and the coal could be economically transported to the surface and cleaned of impurities before marketing. These impurities, referred to as coal refuse, culm, or reject material, are a mixture of coal, rock, carbonaceous and pyritic shales or slates, etc. Because this material has no immediate use, it is disposed of as economically as possible and in such a manner that the disposal does not interfere with the operation. Very often these disposal sites also become the dump for other discarded items, such as grease-soaked rags, grease and oil containers, paper and cardboard, electrical wire and cable, wornout equipment, timber and lumber, and other junk.

Emissions in 1970 amounted to an estimated 200,000 metric tons of sulfur oxides, 110,000 tons of particulates, 340,000 metric tons of carbon monoxide, 68,000 metric tons of hydrocarbons, and 34,000 metric tons of nitrogen oxides. No estimates have been projected for FY 1979, but in view of the concern in controlling fires from coal refuse, it is presumed that emissions will be reduced substantially.

Control costs for extinguishing coal-refuse fires are a variable depending on individual conditions. No overall costs estimates have been prepared for this reason.

Origin of Refuse. Most coal refuse comes from two sources: (1) waste rock and other impurities generated during mine development and operation and (2) impurities separated from the coal at the preparation plant. Mine waste accumulation begins with the development of a mine. Large quantities of rock material are extracted in the sinking of shafts and driving of rock tunnels and haulageways before the first ton of coal is mined. The removal of waste rock is a continuing operation throughout the life of many coal mines. The largest volume of solid waste is produced at the preparation plant. Here the coal is crushed, sized, washed, and separated from rock and other impurities to achieve a grade of coal meeting the market demand.

Coal-refuse banks can be ignited by spontaneous combustion, natural causes, and either intentionally or through carelessness by people. Spontaneous combustion is the most common cause of coal-refuse fires. Sixty-six percent of the 292 refuse banks found burning in 1968 are believed to have started by heat spontaneously generated within the pile. This phenomenon results from the oxidation caused by the natural flow of air through combustion refuse material.

Emission Sources and Pollutants

Emissions from coal refuse burning are tabulated below for selected years:

	Thousands Metric Tons Per Year		
	1968	1969	1970
Sulfur oxides	600	200	200
Particulates	400	115	110
Carbon monoxide	1,200	300	340
Hydrocarbons	240	100	68
Nitrogen oxides	48	14	34

No data are available for 1971-1972 emissions. No estimates have been projected for FY 1979, but in view of the high degree of local interest in controlling fires from refuse banks, emissions should continue to decline.

Control Technology and Costs

Emissions from coal-refuse banks in the future depends on three factors:

(1) new legislation or the enforcement of existing legislation regulating the methods of coal refuse disposal,

(2) the level of state activity in extinguishing fires in existing refuse banks, and

(3) the control technology available at coal-fired electrical-generation stations.

Regarding the first factor, it is known that the three states having majority of coal-refuse banks (Kentucky, Pennsylvania, and West Virginia) have enacted laws to prevent and control air pollution from this source.

The level of state effort in controlling these fires is often a function of the refuse bank location. For instance, for fires in anthracite banks in Scranton-Wilkes Barre area were extinguished first in the Pennsylvania program. If control efforts continue in the individual states at the present pace, this pollution source should be largely controlled by 1979.

Coal refuse can be utilized as a fuel for electric-power generation if the volatile content of the refuse is acceptable. At least one utility company has tested the acceptability of this fuel source in its boilers. However, the large-scale applicability of this fuel is hampered by pollution restrictions on burning higher sulfur coals and fuels with low heat content per unit weight of fuel.

The number of new coal-refuse banks will not increase as a function of total coal production. Strip-mining does not generate refuse banks because the material is back filled into the open pit before reclamation. Proposed new Federal mining regulations will probably make this backfilling a uniform practice.

Extinguishing one fire in a burning refuse bank presents a unique problem, making cost generalizations difficult. It is known that in Pennsylvania, estimates of the control costs were once as high as $4 per metric ton. As mote experience in control techniques was gained, the cost of extinguishing a certain bank declined to 80¢ per metric ton.

QUARRYING AND CONSTRUCTION GROUP

Asbestos Industry

Introduction and Summary

Nature of the Product and Process. Asbestos is used in literally thousands of products in a wide variety of applications. The principal properties of asbestos are its long, extremely fine and flexible fibers that are thermally and electrically inert, having high tensile strength and extremely favorable frictional properties. The two major varieties of asbestos are (1) serpentine or chrysotile, and (2) amphiboles which include crocidolite, amosite, anthophyllite, tremalite, and actinolite. Commercially, chrysotile is by far the most important fiber, especially in the spinning grades of fiber.

It has long been recognized that asbestos fibers are a health hazard, and that the primary danger arises from inhalation. Because of their fine structure and low density, asbestos fibers may be airborne for significant distances and thus create an air-pollution problem. In addition, the fibers are not destroyed by any known environmental process.

Asbestos normally is handled by air conveyance during processing. The air conveying system must be tightly controlled to protect workers and to recover the asbestos. Once asbestos is mixed with a liquid medium there are minimal problems with emissions until the finishing process. Any operation such as breaking, grinding, or polishing required to produce a product usually will create emissions. There is no agreement as to whether free asbestos is released in any specific case, or whether any exposure potential is involved. In this study, it is assumed that these emissions must be controlled just as if they were free asbestos emissions.

Emissions and Control Costs. Emissions in FY 1971 are estimated at 6000 metric tons, increasing to 6500 metric tons in FY 1979. With further controls, emissions in FY 1979 would be reduced to 165 metric tons, a reduction of 97.3 percent.

Investment costs for existing and new facilities from FY 1971 to FY 1979 to control emissions are estimated at $11.4 million. Annual costs are estimated at almost $4 million, and cash requirements are about $28 million.

Industry Structure

Characteristics of the Firms. The asbestos industry covers three major activities: mining of ore, milling of ore, and the manufacture of asbestos products. The industry comprises a few larger, vertically integrated firms and a sizeable number of firms engaged in one or more specialized fields from mining to manufacture of the thousands of products containing asbestos.

Current Capacity and Growth Projection. In 1971, apparent consumption of asbestos in the United States was 690,000 metric tons. Domestic production amounted to 119,000 metric tons; imports, largely from Canada, were 619,000 metric tons and exports were 49,000 metric tons.

Mining. There are nine asbestos mines in the United States, with four being in California, three in North Carolina, and one each in Arizona and Vermont. California mines accounted for 67 percent of the asbestos mined in 1971, followed in order by Vermont, Arizona, and North Carolina.

Milling. There are nine plants milling asbestos in four states as follows

State	Number of Plants	1970 Estimated Capacity, metric tons
Maryland	1	181
Arizona	3	2,180
California	4	87,200
Vermont	1	59,000

Nine firms make up the industry. Four of them are large, vertically integrated firms that make a wide range of asbestos and other products. These firms can use their total U.S. asbestos fiber production for making finished products to be used by various consumers and industry. The other firms are small and sell their output on the open market. An annual growth rate of 1.6 percent has been projected, giving an estimated capacity of about 173,000 metric tons in FY 1979.

Manufacture of Asbestos-Containing Products. In this category is an extremely broad and diverse group of items that contain significant quantities of asbestos fibers. It is estimated that some 3,000 items used in the U.S. contain asbestos. These include asbestos cement products, floor tile, friction materials, asbestos paper, and asbestos textiles. So far as emissions are concerned these products can be divided into two categories. Either asbestos remains as essentially free fiber throughout the process and in the final product, or the asbestos is wetted or bound into a matrix at an early stage of processing. Production of asbestos textiles is the major manufacturing process in the first category.

The capacity of the asbestos industry in 1971 and expected growth to 1979 of asbestos products by major sectors, based on an expected annual growth rate of 5 percent, is shown below.

		1000 Metric Tons of Asbestos					
Process/Product	Number of Plants	1971	1972	1973	1974	1975	1979
Cement Pipe and Building Products	48	172.4	181.0	190.1	199.6	209.6	254.8
Floor Tile	18	124.1	130.4	136.8	143.7	150.9	183.5
Felts and Papers	29	96.5	101.4	106.5	111.8	117.4	142.7
Friction Products	30	69.0	72.4	76.0	79.8	83.8	101.9
Textiles	34	20.7	21.7	22.8	24.0	25.2	30.5
Miscellaneous*	--	206.9	217.2	228.1	239.5	251.5	305.7

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*There are hundreds of plants using asbestos in manufactured products. For example, there are approximately 300 firms manufacturing packing and gaskets.

Emission Sources and Pollutants

Principal emission sources of asbestos are from air conveying systems used in processing and finishing processes involving breaking, grinding, or polishing required in making asbestos products. There is no agreement as to whether free asbestos is released in any specific case, or whether any exposure is involved. In this study, it is assumed that all these emissions must be controlled just as if they were free asbestos emissions.

Asbestos emissions from manufacture of asbestos-containing products can be divided into two categories. Either asbestos remains as essentially free fiber throughout the process and in the final product, or the asbestos is wetted or bound into a matrix at an early stage of processing.

Production of asbestos textiles is the major manufacturing process in the first category. In this process, the long asbestos fibers are fluffed and then blended with a cellulosic fiber. The subsequent processing involves carding, lapping, roving, spinning, and weaving or braiding, and is performed on equipment similar to standard textile machining requiring frequent access when operating.

Virtually all other processes fall in the second category. Significant emissions may occur in finishing operations for cement pipe and building products, felts and papers, and friction products. Asbestos emissions from floor-tile manufacture are essentially nil as soon as the fibers are mixed with the hot vinyl or asphalt. In friction products, the processes of molding and curing are usually pollution free, while the finishing processes involving shaping, cutting, and sawing may give rise to some emissions.

In sprayed insulation, asbestos emissions arise from handling the dry asbestos - cement mixture, escape of nonwetted fiber, overspray and splash, and disposal of wastes. There are various measures of partial control such as premixing the materials in the bag used to ship asbestos, enclosing the sprayed area, and careful control over disposal of wastes. Perhaps the best control is to ban the use of asbestos for this purpose and substitute materials such as mineral wool, ceramic fibers, vermiculate, or other similar inorganic fibers.

Controlled and uncontrolled emissions for selected years are:

Fiscal Year	Mode	Particulates, metric tons
1971	Without further control	6,000
1975	Without further control	6,500
	With further control	165
1979	Without further control	7,070
	With further control	191

Control Technology

The only acceptable control technique for asbestos from manufacturing-process emissions appears to be the use of a fabric filter. Fabric filters are considered very good for asbestos-emission control because:

(1) Any asbestos fiber captured need not be further processed for reuse.

(2) Once the fabric is coated with asbestos, the filter becomes even more efficient achieving almost total (95+ %) check removal of fibers.

(3) Baghouses provide collection efficiency equal to or better than any other collection system.

(4) Baghouses cost less to buy, maintain, and operate than any system with comparable asbestos collection efficiency.

Control Costs

Estimated control costs for model plants for milling and major manufacturing processes are shown in Table IV-28. In milling operations, estimated investment costs are based on an evaluation of control requirements on existing facilities. Expected costs per metric ton of asbestos vary on factors other than size of plant, but are generally lower for the larger size operations.

TABLE IV-28. COSTS OF CONTROL FOR SELECTED MODEL PLANTS FOR THE ASBESTOS INDUSTRY

Model Size, 1000 tons/day		Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/daily ton		
		expected	min	max	expected	min	max	expected	min	max
Milling	0.02	0.98	0.72	1.26	0.43	0.31	0.55	21.5	15.5	27.5
	0.07	0.66	0.49	0.85	0.29	0.20	0.36	4.1	2.9	5.1
	0.19	3.82	2.81	4.95	1.67	1.27	2.14	8.8	6.7	11.3
	0.76	2.55	1.89	3.30	1.13	0.81	1.44	1.5	1.1	1.9
	2.29	18.73	13.26	24.07	7.20	5.25	9.25	3.1	2.3	4.0
	6.20	64.96	47.00	83.03	26.65	19.49	34.02	4.3	3.1	5.5
	22.88	73.59	55.20	95.88	29.14	21.22	36.85	1.3	0.9	1.6
	61.9	254.79	193.61	326.82	106.64	78.66	135.28	1.7	1.3	2.2
Cement Products	1.35	20.17	15.28	25.46	6.63	4.86	8.50	4.9	3.6	6.3
	3.96	33.58	23.88	42.29	12.04	8.84	15.23	3.0	2.2	3.8
Tiles	2.59	5.58	4.05	7.01	1.82	1.33	2.33	0.7	0.5	0.9
	7.60	9.83	7.30	12.80	3.29	2.45	4.27	0.4	0.3	0.6
Felts and Papers	1.25	14.92	10.76	18.89	4.99	3.62	6.18	4.0	2.9	4.9
	3.67	24.95	17.55	31.75	8.29	5.89	10.54	2.3	1.6	2.9
Friction Products	0.86	13.11	9.30	16.69	4.30	3.09	5.52	5.0	3.6	6.4
	2.54	21.37	15.73	27.01	7.13	5.17	8.94	2.8	2.0	3.5
Textiles	0.23	36.16	26.17	46.82	12.09	8.70	15.55	52.6	37.8	67.4
	0.67	61.60	45.10	77.40	20.16	14.79	25.43	30.1	22.1	38.0
Miscellaneous	0.08	0.89	0.64	1.14	0.29	0.21	0.36	3.6	2.6	4.5
	0.23	1.42	1.02	1.81	0.49	0.35	0.62	2.1	1.5	2.7

Direct control costs are summarized as follows:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	7.19	6.95	8.08
Annual Costs			
Capital Charges	0.95	0.81	1.05
Operating and Maintenance	1.54	1.31	1.73
Total Annual Costs	2.49	2.12	2.78
Cash Requirements	19.94	17.46	21.73
New Facilities			
Investment	4.16	3.47	4.80
Annual Costs			
Capital Charges	0.55	0.47	0.62
Operating and Maintenance	0.83	0.73	0.93
Total Annual Costs	1.38	1.20	1.55
Cash Requirements	8.39	7.55	9.44

Expected investment costs for new and existing facilities from FY 1971 and FY 1979 are $11.4 million. Annual costs are about $4 million, and cash requirements are $28.3 million.

Asphalt Concrete Processing

Introduction and Summary

Nature of Product and Process. This industry manufactures asphalt concrete which consists of a mixture of aggregates and an asphalt cement binder. Aggregates usually consist of different combinations of crushed stone, crushed slag, sand, and gravel. Asphalt concrete plant processing equipment consists of raw-material apportioning equipment, raw-material conveyors, a rotary dryer; hot-aggregate elevators, screening, weighing, and storage; mixing equipment; asphalt-binder storage, heating and transfer equipment; and mineral-filler-storage and -transfer equipment. The largest sources of particulate emissions are the rotary dryer and the screening, weighing, and mixing equipment. Additional sources which may be significant particulate emitters if not properly controlled are the mineral-filler-loading, -transfer, and -storage equipment, and the loading, transfer, and storage equipment that handles the dust collected by the emission control system.

Asphalt-concrete production is essentially a "batch" type operation. Continuous-mix plants represent only 10 percent of the industry.

In 1972, there were approximately 4,800 plants which produced an estimated 295 million metric tons of paving material with a dollar value of $2,038 million. The industry employs about 300,000 people.

The current production of the industry--295 million metric tons of asphalt paving per year--is expected to grow at an estimated compounded annual rate of 3.0 percent to 323 million metric tons in 1975 and 364 million metric tons in 1979. Because of batch-type operations and seasonal nature of production, the average plant operates only 1500 hours per year at 50 percent of plant capacity.

Emissions and Control Costs. According to EPA Publication NO. AP-42 (April, 1973), the uncontrolled emissions from asphalt batching plants are 23 kg of dust per metric ton of product. Uncontrolled emissions in FY 1971 are estimated at 6.6 million metric tons. In FY 1979, uncontrolled emissions are estimated at 8.4 million metric tons, while with controls emissions are estimated at about 4,500 metric tons. A reduction of 99.9 percent.

Investment costs from FY 1971 to FY 1979 are estimated at $600 million. Annualized costs in FY 1979 are estimated at $120 million, and cash requirements from FY 1971 to 1979 are estimated at $1 billion.

Industry Structure

Characteristics of the Firms. The hot-mix asphalt industry is composed of firms engaged in the production and laydown of asphalt concrete. There are approximately 1320 companies operating 4800 plants in the United States. Plant size distribution is shown below. As shown in the table, 60 percent of the capacity is located in plants having an average size of 182 metric tons per hour. Based on a survey conducted by the National Asphalt Pavement Association (NAPA) in 1972, covering 1081 plants, 76 percent were stationary plants and 24 percent were portable plants. Continuous mixers comprised 24 percent of the portable plants, compared with only 2 percent for stationary plants.

Size Range, metric tons/hr	Average Size, metric tons/hr	No. of Plants	Percent Capacity
82 - 100	91	694	6.6
101 - 263	182	3,122	59.5
264 - 282	273	520	14.9
283 - 499	391	464	19.0
		4,800	100.0

Current Capacity and Growth Projections. Production of hot-mix asphalt in 1972 was estimated at 295 million metric tons, based on the fact that asphalt cement constitutes approximately 1/18 of the weight of hot-mix asphalt. Assuming an estimated annual growth rate of 3 percent, production in FY 1979 will be about 364 million metric tons. Because of the batch-type operations and seasonal nature of the business, capacities are appreciably higher than annual production rates. Current capacity has been estimated by NAPA at over 1.18 billion metric tons.

Emission Sources and Pollutants

Dust particulates from the aggregates used in making asphalt concrete are the predominant emissions. The principal source is the rotary drier. Other major sources are the hot-aggregate elevators and vibrating screens.

Estimated emissions with and without controls for selected years are as follows:

Fiscal Year	Mode	Particulates, million metric tons
1971	Without further control	6.6
1975	Without further control	7.5
	With further control	0.056
1979	Without further control	8.4
	With further control	0.005-0.09

Control Technology

Practically all plants use primary dust collection equipment such as cyclones, or settling chambers. These chambers are often used as classifiers with the collected aggregate being returned to the hot-aggregate elevator to combine with the dryer aggregate load.

The gases from the primary collector must be further cleaned before venting to the atmosphere. The most common secondary collector is expected to be the baghouse, although venturi scrubbers are used in some plants. The baghouse allows dry collection of dust which can be returned to the process or hauled away to a landfill although land use legislation makes that more and more difficult. The venturi scrubber makes dust hauling expensive due to the wetting of the dust. Also, the use of large settling ponds and possible need for water treatment discourage use of venturi scrubbers.

Continuous mixers represent about 10 percent of total capacity. Control equipment is assumed to be similar to that required for batch-type plants.

Control Costs

Estimated control costs for model plants are shown in Table IV-29.

A summary of the direct control costs for asphalt concrete processing is as follows:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	479	329	650
Annual Costs			
Capital Charges	78	57	103
Operating and Maintenance	17	15	20
Total Annual Costs	95	72	123
Cash Requirements	814	610	1047
New Facilities			
Investment	125	72	178
Annual Costs			
Capital Charges	20	13	27
Operating and Maintenance	4	4	5
Total Annual Costs	24	17	32
Cash Requirements	182	115	249

Investment Costs from FY 1971 to FY 1979 for existing and new facilities are estimated at $600 million. Annual costs in FY 1979 are estimated at $125 million, and total cash requirements from FY 1971 to FY 1979 are estimated at $1 billion.

TABLE IV-29. ASPHALT CONCRETE PROCESSING COSTS OF CONTROL FOR THE MODEL PLANTS

	Model Size, metric ton/hr	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/Hourly ton			Control Equipment
		expected	min	max	expected	min	max	expected	min	max	
Wet Scrubber	91	60	28	90	12	6	17	132	66	187	Wet Scrubber
	182	70	33	109	14	8	21	77	44	115	"
	273	81	39	126	16	9	24	59	33	88	"
	391	87	38	132	18	9	26	46	23	66	"
Fabric Collectors	91	92	46	142	18	10	27	198	110	297	Fabric Filter
	182	105	57	155	21	12	30	115	66	165	"
	273	117	59	172	23	13	33	84	48	121	"
	391	116	56	178	23	12	35	59	31	90	"

Note: The model size is based on retaining the feed in the batch mixer for 60 seconds. If the retention time is only 40 seconds, then the sizes will change to 150,300,450, and 600 tons/hours respectively.

Cement Industry

Introduction and Summary

Nature of Product and Process. Portland cement, which accounts for approximately 96 percent of cement production in the United States is a blend of various calcareous, argillaceous, and siliceous materials, such as limestone, shell, chalk, clay, and shale. As the binder in concrete, portland cement is the most widely used construction material in the United States.

The four major steps in producing portland cement are: (1) quarrying and crushing, (2) blending and grinding, (3) heating the materials in a rotary kiln to liberate carbon dioxide and cause incipient fusion, and (4) fine-grinding of the resultant clinker, with the addition of 4 to 6 percent gypsum. Finished cement is shipped either in bulk or in bags. All portland cement is produced by either a wet or dry grinding process; the distinguishing characteristic being whether the raw materials are introduced into the kiln as a wet slurry or as a dry mixture.

Emissions and Control Costs. In FY 1971, emission of particulates without controls are estimated at 10 million metric tons. In FY 1979, these emissions without controls are estimated to increase to 11.7 million metric tons, compared with 11,800 metric tons with controls. Uncontrolled emissions of SO_x are minimal and are estimated to increase from 218,000 metric tons in FY 1971 to 427,000 metric tons in FY 1979.

Cost of control of particulate emissions are estimated to require an investment (FY 1971-FY 1979) of $444 million. Annualized costs are estimated at about $130 million, and cash requirements from FY 1971 to FY 1979 are estimated at about $1.1 billion.

Industry Structure

Characteristics of the Firms. In 1971 there were 170 plants producing portland cement clinker plus five plants operating grinding mills to produce finished cement. There are 51 companies located in 41 states. Fifty percent of industry capacity is owned by multiplant companies and the 8 leading companies account for about 47 percent of the total. The industry is capital intensive. Overcapacity, with consequent low profit margins, inhibited modernization and construction of new plants during the past several years, and more stringent air-pollution regulations have increased both capital and operating costs. Recent trends are to increased size of operations through installation of larger kilns to replace old, marginal kilns, permitting more economic and efficient pollution control

Current Capacity and Growth Projections. Cement manufacturing plant capacity and size distribution is shown below. Estimated 1971 capacity of 77 million metric tons is expected to increase to about 91 million metric tons in FY 1979 based on a 2 percent average annual growth. Size distribution is expected to shift upwards as new plants are constructed and existing plants modified or closed, so the total number of plants is expected to remain about the same. It is also assumed that there will be no major shift in production capacity percentages between dry and wet grinding processes, which is presently estimated at 59 percent by the wet process.

Size Range, metric tons/day	Number of Plants	Number of Kilns	Total Annual* Capacity, million metric tons	Percent of Total Capacity
Less than 513	6	10	0.8	1.0
514-1025	49	98	12.3	15.8
1026-1538	65	170	27.0	34.6
1539-2051	28	95	16.5	21.1
2052-2564	11	37	8.7	11.2
2565 and	11	56	12.6	16.3
	170	466	77.9	100.0

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* Based on 334 day operation.

Emission Sources and Pollutants

Primary emission sources are from dry-process blending and grinding, kiln operation, clinker cooler, and finish grinding. Other sources include the feed and materials-handling systems. The primary air pollutant is dust particulates. The other air pollutant is SO_x from sulfur components contained in the ores or from sulfur contained in coal and oil used to heat the blend of raw materials to produce the clinker. Estimated dust-emission factor for an uncontrolled dry-process plant is 170 kg per metric ton of cement, compared with 130 kg per metric ton for the wet-process plant, giving an average emission factor of 146 kg per metric ton of product.

Estimated controlled and uncontrolled emissions for selected years are:

Fiscal Year	Mode	Millions Metric Tons/Year	
		Particulate	SO_x
1971	Without further control	10.0	0.22
1975	Without further control	10.8	0.33
	With further control	0.133	0.33
1979	Without further control	11.7	0.43
	With further control	0.015	0.43
1979	Percent Controlled	99.9	

Control Technology and Costs

Where ambient gas temperatures are encountered such as grinding, conveying, and packaging, fabric filters are used almost exclusively. The greatest problems are encountered with high-temperature gas streams which contain appreciable moisture.

Both fabric filters and electrostatic precipitators are used in controlling dust emissions from kilns. The condensation problems from the high moisture content in the wet-process plant may be overcome by insulating the ductwork and preheating the systems on start-up.

In the past, industry practice has been to employ mechanical collectors for controlling dust emissions from clinker coolers. Tests on the few installations of baghouses and electrostatic precipitators indicate that it is possible to meet the new source performance standard by either method.

Costs for installation of baghouses and electrostatic precipitators for various model-size plants are shown in Table IV-30. Expected investment and annualized costs for electrostatic precipitators are slightly lower, but variations in plant site and operating conditions could make baghouses the lower cost installation.

Direct control costs for the cement manufacturing industry, from FY 1971 to FY 1979 are summarized as follows:

	FY 1971 - FY 1979 $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	328	277	381
Annual Costs			
Capital Charges	36	31	42
Operating and Maintenance	58	53	62
Total Annual Costs	94	84	104
Cash Requirements	865	775	960
New Facilities			
Investment	116	87	145
Annual Costs			
Capital Charges	12.8	10.0	15.5
Operating and Maintenance	21.8	18.9	24.5
Total Annual Costs	34.6	28.9	40.0
Cash Requirements	234	190	276

Expected investment costs are estimated at $444 million. Annual costs are almost $130 million and cash requirements from FY 1971 to FY 1979 are estimated at $1.1 billion.

TABLE IV-30. COSTS OF CONTROL FOR THE MODEL PLANTS CEMENT MANUFACTURING

Model Size, million metric ton/yr	Investment $1,000			Annualized Cost, $1,000			Unit Cost, $/metric ton			Control Equipment
	expected	min	max	expected	min	max	expected	min	max	
0.13	1290	747	1858	411	290	532	3.16	2.22	4.09	Baghouse
0.25	1620	882	2263	508	346	650	2.03	1.38	2.60	
0.43	1933	1009	2740	589	406	765	1.37	0.94	1.78	
0.60	1980	1059	2845	633	433	825	1.05	0.72	1.38	
0.77	2189	1154	3169	686	465	901	0.89	0.60	1.17	
0.93	2411	1365	3446	737	522	959	0.79	0.56	1.03	
0.13	1239	671	1758	326	220	428	2.50	1.69	3.29	Electrostatic Precipitator
0.25	1517	826	2104	401	271	522	1.60	1.08	2.09	
0.43	1711	989	2417	462	315	598	1.07	0.73	1.39	
0.60	1894	1186	2655	502	362	656	0.84	0.60	1.09	
0.77	2000	1140	2817	542	375	697	0.70	0.49	0.91	
0.93	2130	1118	3050	571	383	754	0.61	0.41	0.81	

Crushed Stone, Sand, and Gravel

Introduction and Summary

Nature of the Products and Processes. The quarrying of vast tonnages of stone, sand, and gravel results in substantial amounts of dust being generated and carried into the atmosphere. More importantly, the crushing of stone and screening of aggregates releases large quantities of particulates. About one-half of the particulates generated by these operations settle out in the plant. However, the remaining fine particulates became suspended in the atmosphere and thus are subject to EPA regulations.

Emissions and Control Costs. Emissions of particulates in FY 1971 are estimated at 2.7 million metric tons, increasing to 3.5 million metric tons in FY 1979.

No control methods have been established for handling these emissions, however, increasing concern and local constraints have led numerous firms to install covered bins, hoppers, and chutes and filter systems to collect dust. Water sprays, with and without dust-control chemicals are also used at conveyor feed and transfer points, with quarry drills, on roads, etc.

Industry Structure

Characteristics of the Firms. In 1971, there were 4729 quarries in the United States producing crushed stone. Of these quarries, about one-half produced 45,000 metric tons per year, or less, while the 185 largest quarries produced an average of 1,515,000 metric tons per year. The vast bulk of the crushed stone was used by the construction industry, primarily as aggregates. About 71 percent of the crushed stone was limestone and dolomite, of which 16 percent was used in cement manufacturing, 5 percent for agricultural purposes and 4 percent each for lime manufacturing and as flux stone.

In 1971, there were 5738 commercial sand and gravel plants. Of these, one-half produced 45,000 metric tons per year, or less, while the 70 largest produced an average of 1,470,000 metric tons per year. Government and contract producers accounted for about 16 percent of the production. The construction industry used 96 percent of the total output largely as aggregate in building and paving materials.

Current Capacity and Growth Projections. In 1971, production of crushed stone was 795 million metric tons. An annual growth rate of 3 percent is projected from FY 1971 - FY 1979, indicating a production of almost 1.0 billion metric tons in FY 1979.

In 1971, production of sand and gravel was almost 836 million metric tons, a decline from the 1970 output of 858 million metric tons because of a reduction in production by government and contractor operations amounting to 58 million metric tons. Output from commercial operations increased by 36 million metric tons although the number of producers declined from 5918 to 5738. Trends to larger, more efficient operations are expected to continue as better deposits become depleted and operations are inhibited by urban expansion and the cost of land rehabilitation. An average annual growth rate of 3 percent projected indicates an output of about 1.05 billion metric tons in FY 1979.

Emission Sources and Pollutants

Crushed Stone. Quarrying operations, involving mining, crushing, screening, and conveyor systems are the major sources of particulate emissions. Total particulate emissions at about 6 kg per metric ton about one-half of which settles within the confines of the plant.

Sand and Gravel. Quarrying operations involving mining, screening, and conveyor systems are the major sources of particulate emissions. Total particulate emissions are estimated at 0.05 kg per metric ton.

Estimated uncontrolled emissions from crushed stone, sand and gravel for FY 1971 to FY 1979 are as follows.

Fiscal Year	Mode	Particulates, millions metric tons
1971	Without Further Control	2.7
1975	Without Further Control	3.1
1979	Without Further Control	3.5

Improved dust-collection methods such as covering screens, conveyors, bins, hoppers, and chutes with installation of a system to collect and contain dust; and water sprays, with and without dust-control chemicals are being used in some plants. Further improvements may be expected but no estimates can be made of costs of control until standards are established.

Lime Manufacture

Introduction and Summary

Nature of the Product and Process. Lime is formed by the high-temperature calcination of limestone, or dolomitic limestone to expel CO_2 forming quicklime (CaO). Hydrated lime is made by the addition of water to the lime. Dead-burned (refractory) dolomite is formed by the calcination of dolomite. About 73 percent of lime is produced in rotary kilns, which are of two basic types -- the "long rotary kiln" and the "short rotary kiln with external preheater". Vertical kilns are used to supply the balances, Virtually all new production is by the rotary process.

Major individual uses of lime are for basic oxygen steel furnaces, alkalies, water purification, other chemical uses, and refractory dolomite.

Emissions and Control Costs. In FY 1971, particulate emissions are estimated at 1.8 million metric tons, increasing to 2.1 million metric tons in FY 1979. Controlled emissions in FY 1979 are estimated at 625,000 metric tons.

Investment costs for controls from FY 1971 to FY 1979 are estimated at $61 million. Annual costs are estimated at $13 million, and cash requirements from FY 1971 to FY 1979 are estimated at $125 million.

Industry Structure

Characteristics of the Firms. The U. S. lime industry is conventionally divided into two sectors -- open market and captive. Approximately 35 percent of the output is consumed by the producers, while the remaining 65 percent is sold in the open market. The use of lime is widespread, primarily as a chemical. Other major uses were as construction and refractory materials. Agricultural use has declined to about 1 percent of the total. Plants are localized in 41 states and Puerto Rico. Plant size distribution in 1971 is shown in the tabulation below. Recent trends are toward closing of small, old plants and to replace old kilns with larger units.

Plant Size, metric tons	Number of Plants	Output	
		Thousand metric tons	Percent
Less than 9,090	30	125	1
9,090 to 22,725	37	636	3
22,725 to 45,450	37	1276	77
45,450 to 90,900	26	1614	9
90,900 to 181,800	25	3459	19
181,800 to 363,650	26	6559	37
More than 363,600	7	4280	24

Current Capacity and Growth Projections. Current production is believed to be close of capacity. In 1972, producers at 186 plants sold or used 18.5 million metric tons. Growth in the demand for lime has been projected at 4 percent per year, which would indicate a demand of 23.8 million metric tons in FY 1979. Should the use of lime in the removal of SO_x from stack gases become standard practice, the demand will be increased substantially. The number of plants has declined from 195 in 1970 to 186 in 1972. Further consolidation may be expected to economically justify the increased cost of pollution controls.

Emission Sources and Pollutants

Atmospheric emissions from lime manufacture are primarily particulates from crushing the limestone to kiln size, calcining the limestone in a rotary or vertical kiln, crushing the lime to size, and fly ash if coal is used in calcination. Other emissions, such as SO_x, are determined by the type of fuel used.

Uncontrolled emissions from rotary kilns are about 100 kg per metric ton of lime processed, compared with 4 kg per metric ton from vertical kilns. However, economics favor use of the rotary kiln, and virtually all new and expanded production is expected to be by that method.

Estimates of controlled and uncontrolled emissions for selected years are as follows:

Fiscal Year	Mode	Particulates, million metric tons
1971	Without Further Control	1.8
1975	Without Further Control	2.1
	With Further Control	.02
1979	Without Further Control	2.7
	With Further Control	.625

Control Technology and Costs

Gases leaving a rotary kiln are usually passed through a dust-settling chamber where the coarser material settles out. On many installations, a first-stage primary dry cyclone collector is used. The removal efficiency at this stage can vary from 25 percent to 85 percent (by weight) of the dust being discharged from the kiln.

The selection of a second stage to meet the high efficiency level of 0.03 gr/acf may be either a high-energy wet scrubber, fabric filter, or electrostatic precipitator. While the electrostatic precipitator has a higher capital cost, this may be more than offset in specific installations by lower operating and maintenance costs.

It is believed that vertical kilns can suppress particulate emissions to allowable limits with baghouses, scrubbers, or cyclone scrubber combinations. In the latter cases efficiencies of 98.5 percent and above have been reported.

Control Costs

A summary of the estimated direct control costs for lime manufacture from FY 1971 to FY 1979 is as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	54	46	61
Annual Costs			
Capital Charges	6.6	5.8	7.4
Operating and Maintenance	5.0	4.8	5.4
Total Annual Costs	11.6	10.6	12.8
Cash Requirements	113	101	123
New Facilities			
Investment	7.0	6.1	7.9
Annual Costs			
Capital Charges	0.88	0.78	0.98
Operating and Maintenance	0.82	0.58	1.08
Total Annual Costs	1.70	1.36	2.06
Cash Requirements	12	10	17

FOOD AND FOREST PRODUCTS GROUP

Foreword to Grain Industry

This investigation covers estimated control costs for grain handling and feed manufacture, which are major sources of air pollution in the grain mill industries. Other segments of the industry include:

Flour Milling
Cereal Manufacture
Rice Milling
Wet-Corn Milling
Blended and Prepared Flour
Soybean Processing.

Midwest Research Institute (MRI) in its recent investigation estimated costs of air-pollution control for the total industry as follows:

	Investment, million dollars	Annual Cost, million dollars
Elevators	1,015.0	188.5
Feed mills	1,042.0	205.0
Alfalfa plants	10.5	2.2
Wheat milling	75.0	20.5
Rice mills	14.4	3.5
Soybean processing	46.7	12.0
Corn wet milling	5.9	1.7
Other	34.5	6.4
Total	2,244.0	439.8

Their estimates for grain elevators and feed-mill controls, compared with Battelle's findings in this study are as follows:

	Investment ($ million)	Annual Cost ($ million)
MRI	2057	394
BCL	1950	330

Based on MRI's estimates, grain handling and feed manufacturing account for 91.7 percent of the investment requirement and 89.5 percent of the annual cost. Using these percentages and BCL estimates for FY 1971-FY 1979 costs of air-pollution control for grain handling and feed milling, total costs for the grain-mill industries would require an investment of $2575 million and an annual cost of $450 million.

Feed Mills

Introduction and Summary

Nature of the Product and Process. Feed manufacture is the process of converting the grains and other constituents into the form, size, and consistency desired in the finished feed. Feed milling involves the receiving, conditioning (drying, sizing, cleaning), blending, and pelleting of the grains, and their subsequent bagging or bulk loading.

Emissions and Control Costs. The primary emissions are feed-mill dusts consisting of complex mixtures of bristles and other particles from the outer costs of grain kernels, spores of smuts and molds, insect debris, pollen, field dust, and various organic and inorganic materials.

Total emissions without further controls are estimated at 894,500 metric tons in FY 1971, increasing to 1.12 million metric tons in FY 1975, and 1.30 million metric tons in FY 1979. With further controls, emissions could be reduced to an estimated 1180 metric tons in FY 1975, and 1360 metric tons in FY 1979.

Direct control costs (FY 1971-1979) will require an expected investment of $1377 million and an annualized cost of $255 million. Cash requirements are estimated at $2346 million.

Industry Structure

As of July 1, 1973, the number of existing feed mills was 7,763 plants with a total capacity of 129 million metric tons per year. For the present study, these have been grouped into the following size categories:

Size Range, metric tons/day	Capacity, million metric tons/year*	Percent of Total Capacity	Number
0-44	43.4	33.5	4,269
45-90	62.6	48.3	2,790
91-136	23.6	18.2	704

* Based on operating 40 hours per week and 50 weeks per year.

Production of feed increased by 4-1/2 percent between 1969-1973, from 92 million to 107 million metric tons, and growth between 1973 and 1979 will be 5 percent compounded annually, amounting to 144 million metric tons in 1979. Industry capacity is expected to increase by the addition of new plants and/or expansion of current mills when production reaches 85 percent of capacity and will continue to expand at the same rate as output increases. This will require an increase in capacity to 169 million metric tons in 1979.

Small plants (primarily those less than 45 metric tons/day) will decrease by 15 percent between 1969-1979. These plants will be replaced largely by plants in the 91 metric ton/day capacity range.

Emission Sources and Pollutants

The primary emission from feed manufacture is dust or particulates. The factors affecting its emissions include the type and amount of grain handled, the degree of drying, the amount of liquid blended into the feed, the type of handling (conveyor or pneumatic), and the degree of control. An indication of the relative importance of the emission sources in a typical feed mill are:

Operation	Percent
Rail unloading	25
Cyclones collectors	21
Truck unloading	15
Truck loading (bulk loadout)	11
Bucket elevator leg vents	5
Bin vents	5
Scale vents	3
Grinding system (feeder, spills)	4
Incinerator (waste paper)	2
Small boiler (oil)	1
Rail car loading (bulk loadout)	1
Miscellaneous (conveying spouts, pellet mills, feeder lines)	7
Total Feed Mill Dust Emission	100

Unloading of bulk ingredients is generally acknowledged to be one of the most troublesome dust sources in feed mills. Centrifugal collectors used for product recovery and dust control represent the second largest emission source. Cyclones on pellet coolers and cyclones used as product collectors on pneumatic conveying systems are the most important sources in this category. Pellet coolers can be operated without being notably dusty; however, where a powder, such as cottonseed meal, is being used to prevent caking of the pellets, dust emissions may be profuse. Dust emissions from storage bins depend upon the size of the bin, the rate at which it is filled, and the method of conveying the material to the bins. A large bin which is being filled slowly through a chute from a distributor can act as its own settling chamber. Bulk loading, particularly loading of meal, can be a significant source of dust. Loading through chutes into either rail cars or trucks exposes the product to the same winnowing action of the wind that blows dust from raw materials during unloading. Loading a boxcar with a flinger which throws feed from the door to the end of the car can be a very dusty operation.

Factors affecting emission rates from ingredient receiving area of a feed mill include the type of grain and other ingredients handled, the methods used to unload the ingredient, and the configuration of the receiving pits.

Hammermills present the greatest dust problem due primarily to their product conveying system. Most hammermills are installed using a conventional attached or separate fan and cyclone collector as the finished-product recovery system, which is the major source of dust in the grain-processing operation. Dust emission is influenced by the type of grinder (standard or full circle screens), products being ground, and the method of conveying finished product.

The pellet coolers are also a major source of dust and they present control problems because of the moisture content of the air stream leaving the coolers. The pellet cooler reduces the moisture content of the material from 17 to 11 percent. The nature of the product is a significant influence on the emissions from the cyclone.

Feed-mill dusts are complex mixtures of bristles and other particles from the outer coats of grain kernels, spores of smuts and molds, insect debris, pollen, field dust, and various organic and inorganic materials.

Estimates of controlled and uncontrolled emissions for selected years are:

Fiscal Year	Mode	Particulates, thousand metric tons
1971	Without further control	895.0
1975	Without further control	1125.0
	With further control	1.2
1979	Without further control	1295.0
	With further control	1.4

Control Technology

Based on an MRI survey of 402 existing feed mills, 88.1 percent of the volume handled in pellet-cooler operations and 56 percent of the volume handled in grinding operations have some type of emission control, largely by use of cyclones. In receiving, transfer, and storage operations roughly one-third of the total volume is controlled by either cyclones or fabric filters, while in shipping only a few installations have installed controls.

However, it is assumed that fabric filters, or their equivalent (e.g., multicyclones might be used in certain installations), will be required as the best available control techniques to meet standards established under the Clean Air Act.

Control Costs

It is recognized that feed mills vary both in processing steps and operating characteristics. Furthermore, the size of feed mills covers a wide capacity spectrum, and operations vary with size. In order to cover the size spectrum cost curves were prepared, on the basis of estimated costs of installing best control equipment and on estimated annual operating and maintenance costs for 45 metric tons per 8 hour day and 180 metric tons per 8 hour day capacity plants.

In determining these costs the following assumptions were made:

- The MRI survey of 402 existing plants is representative of the entire feed mill population.
- The best practical available control technique for feed mills to meet emissions standards is fabric filters.

- Cyclones and other control techniques will be replaced with fabric filters, and fabric filters will be installed on existing plants without controls.
- The cost to install fabric filters on existing plants with no controls is 125 percent of the cost required for control equipment on a new plant, while the cost to replace cyclones and other control techniques on existing plants is 110 percent of the cost required for controls on a new plant.
- The operating costs for controls on existing plants will be the same as the operating cost for new plants.

Using these data and assumptions, costs of control were determined for model sizes of 9,980 metric tons/year, 22,680 metric tons/year, and 33,500 metric tons per year on existing facilities and for 22,680 tons per year on new facilities. These estimated costs are shown in Table IV-31.

A summary of direct control costs for feed manufacture (FY 1971-1979) is as follows:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	1080	981	1182
Annual Costs			
Capital Charges	142	132	154
Operating and Maintenance	57	51	62
Total Annual Costs	199	183	216
Cash Requirements	1897	1822	2031
New Facilities			
Investment	297	247	355
Annual Costs			
Capital Charges	39	33	46
Operating and Maintenance	17	15	19
Total Annual Costs	56	48	65
Cash Requirements	449	388	526

Expected investment costs for existing and new facilities are estimated at $1377 million. Annual costs are estimated at $255 million and cash requirements at $2346 million over that time period.

TABLE IV-31. COSTS OF CONTROL FOR THE MODEL PLANTS, FEED MANUFACTURE

Model Size, metric tons per yr	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/ metric ton per yr		
	expected	min	max	expected	min	max	expected	min	max
Existing Facilities									
9,980	117	101	134	21.2	18.3	24.1	2.12	1.83	2.41
22,680	160	140	180	29.9	26.1	33.8	1.32	1.14	1.49
33,500	188	164	216	35.9	31.1	41.1	1.07	0.92	1.22
New Facilities									
22,680	145	121	173	27.2	23.1	32.0	1.20	1.00	1.40

Grain Handling

Introduction and Summary

Nature of Product and Process. Grain handling comprises the series of grain-storage facilities from delivery by the farmer to the ultimate user. There are two main classifications of grain-storage facilities: country elevators and terminal elevators. Country elevators receive grains from nearby farms by truck for storage or shipment to terminal elevators. Terminal elevators are subdivided into inland and port terminals. Inland terminals receive, store, handle, and load the grain into rail cars or barges for shipment to processors or port locations. Port terminals receive grain and load ships for export.

Grain handling includes a variety of handling operations which emit particulates, consisting largely of dirt and attrition of the grain.

Emissions and Control Costs. Primary emission sources in country elevators involve unloading and loading operations. In terminal elevators, cleaning, drying, and screening of the grains are additional major sources of air pollutants.

Total emissions without further controls are estimated at 683,000 metric tons in FY 1971, and 980,000 metric tons in FY 1979. With further controls, emissions in FY 1975 would be reduced to about 1000 metric tons.

Direct control costs (FY 1971-FY 1979) will require an expected investment of $985 million and an annualized cost of about $150 million. Cash requirements are estimated at $1532 million.

Industry Structure

Characteristics of the Firms. Traditionally, grain handling is considered in terms of series of grain-storage facilities starting from the delivery by the farmer to the ultimate user. These grain-storage facilities, or grain elevators, provide storage space and serve as collection, transfer, drying, and cleaning points. There are two main classifications of grain elevators -- country and terminal elevators. Country elevators receive grains from nearby farms by truck for storage or shipment to terminal elevators or processors. Terminal elevators (this category is subdivided into inland and port terminals), are generally larger than country elevators and are located at significant transportation or trade centers. Inland terminals receive, store, handle, and load these grains in rail cars or barges for shipment to processors or port locations. Port terminals receive grain and load ships for export to foreign countries. It has been noted that particulate emission is a function of both the amount of grain handled and the operations involved in handling. Conversely, the cost of equipment for emission control is a function of the size of facility and operations involved. Consequently, model sizes for types of operations and size of country elevators, inland terminals and port terminals have been selected, ranging from 0 to 1999 thousand bushels (mb), 2000 to 19,999 (mb), and 20,000 to 200,000 (mb) of handling capacity per year.*

Current Capacity and Growth Projections. The number and storage capacities of the country and terminal elevators by state as of September 30, 1972. Size ranges and number of facilities per size range—on the basis of volumes of grains handled—are estimated as follows:

Ranges, thousand bu/yr**	Total Volume Handled, million bu/yr	Percent of Total Volume	Total Number	Average Volume, thousand metric tons/yr
0-1,999	6,209	55.5	7,147	837
2,000-19,999	2,025	18.1	413	4,903
20,000-200,000	2,953	26.4	64	46,141

Further calculations show that the average grain volume handled in 1972 for country elevators was 870,000 bushels; for inland terminals, 4.9 million bushels; and for port terminals, 46.25 million bushels.

Country elevators are estimated to increase the volume handled at a rate of 5 percent per year through 1979. Grain volume for the second and third size range (inland and port terminals, respectively) will increase at the rate of 10 percent during the first year and 5 percent during the subsequent years through 1979.

While the amounts of grain handled in all categories will increase, there will be an actual decrease in numbers of facilities operating. The number of country elevators is estimated to decrease by 25 percent between 1974 and 1979; however, the inland elevators probably will increase by 30 facilities by 1979, and it is estimated that the third category will increase by 7 facilities by 1979.

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* It is understood that very few country elevators fall within the second range while some inland terminal elevators may fall within first capacity range.

** bu/yr = bushels per year

Estimates of the total number of plants and the total volume of grain to be handled in mid-1979 are:

Ranges, thousand bu/yr	Total Volume Handled, million bu/yr	Percent of Total Volume	Total Number	Average Volume New Facilities (1000 bu/yr)
0-1,999	8,320	55.5	5,360	1,000[(a)]
2,000-19,999	2,710	18.1	443	23,000
20,000-200,000	3,960	26.4	71	144,000

(a) This size was used in estimating the cost of control for country elevators because it was assumed that new capacity would be added largely by addition of equipment to existing facilities to increase their capacities to about 1 million bushels per year.

Emission Sources and Pollutants

Grain handling includes a variety of operations which emit differing amounts of air pollutants, primarily particulates. The particulates consist of attrition of the grain kernels and dirt. Hence the amount of dust (particulates) emitted during the various grain-handling operations depends on the type of grain being handled, the quality or grade of the grain, the moisture content of the grain, the speed of the belt conveyors used to transport the grain, and the extent and efficiency of dust-collecting systems, such as hoods and sheds being used.

Almost 75 percent of the uncontrolled emissions is generated in the drying, screening, and cleaning operations.

Estimates of controlled and uncontrolled emissions for selected years are:

Fiscal Year	Mode	Particulates, thousand metric tons
1971	Without further control	683.0
1975	Without further control	798.0
	With further control	0.8
1979	Without further control	981.0
	With further control	1.0

Control Technology

Systems for the control of particulate emissions from grain-handling operations consist of either extensive hooding and aspiration systems leading to a dust collector or methods for eliminating emissions at the source. Techniques which eliminate the sources of dust emissions or which retain it in the process are enclosed conveyors; covers on bins; tanks and hoppers; and maintenance of system's internal pressure below the external pressure so that air flow is in rather than out of the openings.

Control methods are also available to capture and collect the dust entrained or suspended in the air. The dust collection systems generally used are cyclones and fabric filters.

In order to meet the emission standards, it is assumed that fabric filters will be installed on all existing plants that do not have any now, or as replacements for cyclones and other control devices. This assumption yields a conservative value and it may be possible to use other control devices (e.g., multicyclones) in specific cases -- perhaps in some small installations.

Control Cost

Model plant sizes of 870,000, 4.9 million and 46.25 million bushels per year throughput volume were used for existing facilities and 1 million, 23 million, and 142 million bushels per year throughput volume for new or expanded facilities were selected. Investment, annualized and unit costs for these model sizes are presented in Table IV-32.

Direct control costs (FY 1971-FY 1979) for grain handling are summarized as follows:

	FY 1971 - FY 1979, $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	868	731	976
Annual Costs			
Capital Charges	114	98	127
Operating and Maintenance	14	9	18
Total Annual Costs	128	107	145
Cash Requirements	1,353	1,170	1,508
New Facilities			
Investment	117	96	135
Annual Costs			
Capital Charges	15	13	18
Operating and Maintenance	6	5	7
Total Annual Costs	21	18	25
Cash Requirements	179	152	204

Total investment costs are estimated at $985 million, annualized costs at $169 million, and cash requirements at $1,532 million.

TABLE IV-32. COSTS OF CONTROL FOR THE MODEL GRAIN-HANDLING PLANTS

Model Size, thousand bushels/ year	Investment, $1,000			Annualized Cost, $1,000			Unit Cost, $/bushel		
	expected	min	max	expected	min	max	expected	min	max
Existing Facilities									
870	103	84	117	15.6	12.4	17.9	0.018	0.014	0.021
4900	230	183	272	34.8	26.2	42.8	0.007	0.005	0.009
46250	650	516	774	57.5	22.7	87.5	0.001	0.0004	0.002
New Facilities (Expansion)									
1000	44	35	53	9.0	7.1	11.0	0.009	0.007	0.011
23000	474	378	552	61.3	40.0	80.0	0.003	0.002	0.003
142000	1076	873	1268	18.8	49.0	91.1	0.0001	0.0003	0.0006

Kraft Paper Industry

Introduction and Summary

Nature of Product and Process. The pulp and paper industry may be divided into (a) pulp mills and (b) paper and paperboard mills. Compared with the pulping processes, the processes used for making paper and paperboard generally produce relatively little air pollution. Consequently, this analysis focuses primarily on the pulping processes, giving major attention to the most significant form of air pollution from the process used for making the largest volume of pulp.

Pulping involves the processing of fibrous raw materials such as wood, cotton, baggasse, or waste paper into forms suitable for use in the manufacture of paper, paperboard, construction paper, or construction board. The fibrous material used in making paper and paperboard is called pulp. Wood is the major source of the fiber.

Both mechanical and chemical processes are used for making wood pulp. Groundwood pulp, the mechanical pulp produced in largest volume, is manufactured by grinding or shredding wood to free the fibers. In the chemical processes, the binding material (lignin) in the wood is dissolved in one of several chemical solutions to free the fibers. Only chemical processes which account for about 84 percent of the total industry, cause significant air pollution. Two of these processes, Kraft and Semichemical, account for 67 percent and 8 percent of the industry, respectively. The Kraft process is discussed in this section of the report and the Semichemical process is discussed in the following section. Kraft pulping is potentially a serious source of particulates and odor, while Semichemical is a significant source of only sulfur dioxide. Since no standards have been established for odors, only particulate-emission control is evaluated for the Kraft process.

Conventional Kraft pulping processes are highly alkaline in nature and utilize sodium hydroxide and sodium sulfide as cooking chemicals. One modification used for the preparation of highly purified, or high-alpha cellulose, pulp utilizes an acid hydrolysis of the wood chips prior to the alkaline cook; this is the prehydrolysis Kraft process. Kraft processes enjoy the advantages of being applicable for nearly all species of wood and of having an effective means of recovery of spent cooking chemicals for reuse in the process.

Included in the uses of Kraft pulp are the production of linerboard, solid-fiber board, high-strength bags, wrapping paper, high-grade white paper, and food-packaging materials.

Emissions and Control Costs. Main particulate-emission sources in the Kraft process are the recovery furnace, lime kiln, smelting dissolving tank, and the bark boilers. The Kraft pulping economics depend upon reclamation of chemicals from the recovery furnace and lime kiln. Hence, emissions from these processes are controlled to minimize losses of chemicals.

Emissions of particulates without further control are estimated at 5,620,000 metric tons in FY 1971, increasing to 7,287,000 metric tons in FY 1979. With further controls, emissions of particulates are estimated at 270,000 metric tons in FY 1979. Implementation plans for the states of Oregon and Washington are assumed, though boiler emissions fall short of the assumed standard.

Total expected investment and annualized costs, FY 1971-FY 1979, are $234 million, and $78 million, respectively. The estimated cash requirement for this period is $534 million.

Industry Structure

Characteristics of the Firms. The numbers of mills and industry capacity for each of the important types of pulping processes, estimated as of July 1, 1973 are as follows.

Process	Number of Mills	Estimated Capacity, metric tons per day(a)	Annual Capacity for 1973, metric tons		Share of Total Capacity, percent	
Chemical Processes				37,939,000		83.6
Kraft (sulfate)	119	85,425	30,164,000		66.5	
Sulfite	31	6,075	2,114,000		4.7	
NSSC	50	10,385	3,611,000		8.0	
Other	14	5,850	2,050,000		4.5	
Mechanical Processes				7,420,000		16.4
Ground wood	59	12,335	4,281,000		9.5	
Other	16	9,435	3,139,000		6.9	
Total	289			45,359,000		100.0

Source: Paper, Paperboard, Wood Pulp Capacity 1971-1974, American Paper Institute and List of U. S. Pulp Mills as of December, 1972, American Paper Institute.

(a) All capacities are expressed as tons of air-dried pulp (ADP).

The Kraft or Sulfate process dominates both in number of mills and total capacity, with an estimated capacity of 30.16 million metric tons out of a total capacity of 45.36 million metric tons.

The Kraft process plant size distributions are classified into three size ranges: 0-770, 771-1088, and 1089-2359 metric tons ADP per day. The first size range has a total of 68 plants with total capacity of 30,122 metric tons air-dried pulp/day (MTADP/day); the second, 28 plants with 24,621 MTADP/day; and the third, 23 plants with 30,692 MTADP/day; the sum of the three ranges gives a total of 119 plants and a total capacity of 85,435 MTADP/day for the Kraft process. Control cost estimates are based on the following model plant sizes: 454, 907, 1361 MTADP/day. Plant size distribution are as follow.

Range of Mill Capacities, tons per day	Number of Mills	Total Capacity of Mills in Size Range, metric tons per day	Average Mill Capacity, metric tons per day	Model Mill Capacity, metric tons per day	Percent Model Mill is Above Average
0-770	68	30,122	443.0	454	2.4
771-1088	28	24,621	861.2	907	3.2
1089-2359	23	30,692	1,334.5	1361	2.0
Total	119	85,435 (a)			

Source: Lockwood's Directory of the Paper and Allied Trades, 97th Edition, Lockwood Publishing Co., Inc., New York, N.Y., 1973.

(a) Total daily production for all active sulfate pulp mills listed in Lockwood's was 96,340 tons, which was 2.3 percent greater than total estimated sulfate pulp capacity as of July 1, 1973, estimated using data from Paper, Paperboard, Woodpulp Capacity- 1971-1974, compiled and published by the American Paper Institute in 1972. The capacity totals for mills in each size range as tabulated from Lockwood's were adjusted downward multiplying by the factor $\frac{94,175}{96,340}$ so the total in this table corresponds to the estimate based on the API Survey.

In the Kraft process, the digesting liquor is a solution of sodium hydroxide and sodium sulfide. The spent liquor (black liquor) is concentrated, sodium sulfate is added to make up for chemical losses, and the liquor is burned in a recovery furnace, producing a smelt of sodium carbonate and sodium sulfide. The smelt is dissolved in water to form green liquor, to which is added quicklime to convert the sodium carbonate back to sodium hydroxide, thus reconstituting the cooking liquor. The spent lime cake (calcium carbonate) is recalcined in a rotary lime kiln to produce quicklime (calcium oxide) for recausticizing the green liquor.

Current Capacity and Growth Projections. Growth of Kraft pulping is estimated to result from two sources: (1) improvement and expansion of existing plants, and (2) construction of new plants.

As of July 1, 1973, the existing plants have a total capacity of 85,435 metric tons per day. It is estimated that by 1975, net improvements due to modernization, shifts in grades, etc., will provide additional capacity of 476 metric tons per day, while new plants will provide 1179 tons per day to give a total capacity of 87,090 metric tons per day.

From 1975 to 1979, new plant capacity is estimated to increase at a rate of five percent of industry capacity per year, while net improvements are estimated to provide 91 metric tons per day of added capacity each year. From 1975 to 1979, net improvements are expected to total 364 tons per day while new plants will provide a total of 18,416 metric tons per day, giving a total Kraft pulp capacity of about 105,870 metric tons per day by 1979.

Emission Sources and Pollutants

Particulates and gases are emitted from the various sources of Kraft process. Numerous variables affect the quality and quantity of emissions from each source of the Kraft pulping process. There are several sources of emissions in the process and the applicable control technology and attainable efficiencies of the control methods depend on the quantity and quality of emissions. The gaseous emissions occur in varying mixtures, and are mainly hydrogen sulfide, methyl mercaptan, dimethyl sulfide, dimethyl disulfide, and some sulfur dioxide. The sulfur compounds are generally referred to as reduced sulfur compounds. These compounds are very odorous, being detectable at a concentration of a few parts per billion. The particulate emissions, are largely sodium sulfate, and calcium compounds.

The sources of gaseous emissions in Kraft process are the (1) digester relief and blowing, (2) stock washers, (3) oxidation towers, (4) evaporators, (5) recovery furnace, (6) smelt tank, and (7) lime kiln. Particulate emissions are from the Kraft furnace, the lime kiln, the smelt dissolving tank, and the power boiler.

The rates of uncontrolled emissions of particulates and gaseous emissions from various sources of Kraft pulping process have been estimated. As expected, the proportion of coal to bark used in the power boilers will affect the amount of particulate emission; the more the coal fraction fired the greater the particulate emissions.

The process weight-emission limitation concept is considered unapplicable to chemical pulping, because the nature and size range of particulates, as well as the characteristics of the processes are vastly different. Provisions of the Washington and Oregon Regulations applicable to pulp mills are used in this report. The regulations include the following control provisions:

(1) Total Reduced Sulfur (TRS) Compounds from the recovery furnace: No more than 1 kg per metric ton (1972) reduced to no more than 1/2 pound per ton by 1975.

(2) Noncondensible gases from the digesters and multiple effect evaporators: Collected and burned in the lime kiln or proven equivalent.

(3) Particulates from the recovery furnace: No more than 2 kg per metric ton.

(4) Particulates from the lime kiln: No more than 0.5 kg per metric ton.

(5) Particulates from smelt tank: No more than 0.25 kg per metric ton.

The controlled and uncontrolled emissions (in 1000 metric tons per year) from Kraft pulping operations over the period FY 1971 to FY 1979 are as follows:

Fiscal Year	Mode	Particulates
1971	Without Further Control	5,260
1975	Without Further Control	5,903
	With Further Control	229
1979	Without Further Control	7,287
	With Further Control	270

Control Technology

Control methods currently used in the wood pulping industry consist of add-on hardware or process modifications. Various methods are in operation. The methods used in this report are add-on hardware which are widely used. The control methods meet the SIP selected.

Recovery Furnace. The main functions of the Kraft recovery furnace are recovery of chemicals from black liquor and production of steam from the heat of combustion of organic residue in the liquor. The recovery of the flue gases are accomplished by control devices, usually electrostatic precipitators and or scrubbers. To meet the particulate-emission limits, the control device may consist of a primary and a secondary control device. Usually the cost of installation and operation of the primary control device is offset by the recovery of chemicals. Therefore, the cost of control will then be the cost for the installation and operation of the secondary control device. Furthermore, in some situations, the flue gas direct contact evaporator has served the dual purpose of a black-liquor evaporator and particulate-emission control device. In recent years, it has been eliminated or modified in some new installations, being replaced with extended multiple-effect evaporation or operated with hot air rather than flue gas as a source of energy for evaporation.

Three control devices are used to control particulates from the recovery furnace in this report (1) installation of an electrostatic precipitator in series with and located above an existing precipitator, (2) installation of 1304 stainless steel venturi scrubber and a concrete-lined mild-steel separator in series with an existing electrostatic precipitator, and (3) second stage venturi in series with an existing venturi recovery.

The first control technique is estimated to have an annual operating efficiency (AOE) of 99.8 percent with such controls applied to 90 percent* of the Kraft industry. The second control method also has an efficiency 99.8 percent and is applied to 8 percent* of the industry. The third control method achieved about 97 percent efficiency, and applied to 2 percent* of the industry's capacity.

Smelt Dissolving Tank. Control devices used to control particulates from smelt dissolving tank are mesh pads, wet scrubbers, packed towers, and cyclones. Two control devices are used in this report: packed towers and orifice (wet) scrubbers.

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* Percent control applications are estimated by private communication with Russell Blosser of the National Council of The Paper Industry for Air and Stream Improvement, Inc.

Packed towers and orifice scrubbers are estimated to be in use currently by only 15 percent of the industry for smelt-dissolving-tank particulate control. However, they were chosen because of higher efficiency of control: 90 percent AOE for packed towers and 97 percent AOE for orifice scrubbers.

Lime Kiln. Several types of control equipment are available for the reduction of lime kiln particulate emissions. The water scrubber, usually of the impingement or venturi type, is used exclusively in the Kraft industry. However, impingement systems usually are inadequate to meet emission standards. In most instances the higher efficiency (97 to 99 percent) venturi scrubbers will be required. Therefore, venturi scrubbers are used in this report.

Power Boilers. Electrostatic precipitators are not generally suitable for use on bark boilers due to (1) the poor electrical characteristics of bark char and (2) the possibility of fires. Therefore, mechanical collectors account for 95 percent of all systems used in controlling emissions from boilers. Tall stacks also are used.

Most boilers are combination boilers. For this report a combination boiler burning 70 percent coal and 30 percent bark is assumed. The control method selected is a cyclonic scrubber in series with an existing 85 percent mechanical dust collector, which gives AOE of 94 percent.

Control Methods for the New Plants. The particulate-control devices have been selected for each emissions source within a new plant on the basis of efficiency, flexibility, economics, reliability, and adaptability. Each source in the new plant will incorporate the best available control method to meet New Source Performance Standards. New plants must adopt some process changes, like the elimination of the direct contact evaporators between flue gases and black liquor, to minimize gaseous emissions. The following control methods are assumed for each source in a new plant.

Recovery Furnace - Electrostatic precipitator with venturi scrubber in series.

Lime Kiln - Venturi scrubber (99.0 AOE)

Dissolving Tank - Orifice scrubber (95 AOE)

Combination Boiler - Cyclone collector plus cyclonic scrubber.

All new plants are assumed to be in the 850 to 1199 metric-ton-per-day plant capacity range.

Control Costs

For the estimation of control cost the following particulate-control methods are used to control particulate emissions from various sources in the Kraft mill: recovery furnace, (1) electrostatic precipitator added in series with an existing precipitator, (2) venturi scrubber added to an existing precipitator, and (3) a second stage venturi scrubber to an existing venturi; lime kiln, (1) fresh water venturi scrubber; smelt dissolving tank, (1) packed tower and (2) orifice scrubber; combination boiler (30 percent bark and 70 percent coal), (1) cyclonic scrubber added to an existing dust collector.

Summary of the model plants control costs is given in Table IV-33. Also shown are the unit costs. Summary of direct control cost for the Kraft pulp process is:

	FY 1971 - FY 1979 $ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	209	181	241
Annual Costs			
Capital Charges	27	25	31
Operating and Maintenance	40	35	46
Total Annual Costs	67	60	77
Cash Requirements	466	425	521
New Facilities			
Investment	25	20	31
Annual Costs			
Capital Charges	3	3	4
Operating and Maintenance	9	7	11
Total Annual Costs	11	10	15
Cash Requirements	68	59	80

Expected investment for the existing facilities is $209 million, cash requirements are $466 million. The investment for the new facilities is $25 million with cash requirements of $68 million. Annualized costs for the existing facilities are $67 million and $11 million for new facilities in 1979.

TABLE IV-33. COSTS OF CONTROL FOR THE MODEL PLANTS, KRAFT PROCESSES

Model Size, tons/day	Investment, $1,000			Annualized Cost, $1,000			Unit Cost $/ton		
	expected	min	max	expected	min	max	expected	min	max
Kraft Recovery Furnace Electrostatic + Electrostatic Precipitation									
500	913	726	1134	244	193	302	1.38	1.09	1.71
1000	1464	1169	1815	406	319	499	1.15	0.90	1.41
1500	2093	1679	2621	568	462	705	1.07	0.87	1.33
(Venturi Scrubber) + Precipitator									
500	295	201	312	136	107	170	0.77	0.61	0.96
1000	404	315	504	241	193	301	0.68	0.55	0.85
1500	678	550	854	373	295	456	0.70	0.56	0.86
(new Facilities)									
Venturi + Precipitator									
1000	405	319	501	244	194	301	0.69	0.55	0.85
2nd Venturi + Venturi									
500	394	271	430	55	44	69	0.31	0.25	0.39
1000	578	463	714	91	73	113	0.26	0.21	0.32
1500	792	633	971	130	114	159	0.24	0.21	0.30
Kraft Lime Kiln (Venturi Scrubber) (Existing Facilities)									
500	114	91	142	41	32	50	0.23	0.18	0.28
1000	158	129	193	57	45	69	0.16	0.13	0.19
1500	204	164	254	72	57	90	0.13	0.11	0.17
(New Facilities)									
(Venturi Scrubber)									
1000	160	126	199	57	46	71	0.16	0.13	0.20
Kraft Smelt Dissolving Tank (Packed Tower)									
500	62	50	77	21	16	25	0.12	0.09	0.14
1000	99	79	123	34	27	42	0.09	0.07	0.12
1500	139	112	174	47	38	58	0.08	0.07	0.11
Kraft Smelt Dissolving Tank (Orifice Scrubber) (Existing Facilities)									
500	53	43	66	29	23	36	0.16	0.13	0.20
1000	78	61	97	45	36	56	0.13	0.10	0.16
1500	103	83	129	67	53	82	0.13	0.10	0.15
(New Facilities)									
(Orifice Scrubber)									
1000	78	61	97	45	36	56	0.13	0.10	0.16
Kraft Combination Boiler (Existing Facilities)									
500	254	202	316	112	88	138	0.63	0.50	0.78
1000	478	391	586	200	158	244	0.57	0.45	0.69
1500	683	549	852	274	217	342	0.52	0.41	0.64
(New Facilities)									
1000	486	383	603	202	163	248	0.57	0.46	0.70

Neutral Sulfite Semichemical Paper Industry

Introduction and Summary

Nature of Product and Process. Semichemical pulps are produced by digesting with reduced amounts of chemicals, followed by mechanical treatment to complete the fiber separation. The most prevalent semichemical pulping process is the neutral sulfite semichemical process. In this process, sodium sulfite in combination with sodium bicarbonate, or ammonium sulfite buffered with ammonium hydroxide, are used as cooking chemicals. These cooks are slightly alkaline, in contrast to the highly alkaline kraft and highly or moderately acidic sulfite cooks. The semichemical pulping processes are used for production of high yield pulps - ranging from 60 to 85 percent of dry wood weight charged to the digestion vessel - and can include kraft and sulfite processes suitably modified to reduce pulping action in order to produce higher than normal yield pulps.

Semichemical pulps are used in the preparation of corrugating medium, coarse wrapping paper, linerboard, hardboard, and roofing felt as well as fine grades of paper and other products.

Emissions and Control Costs. Air emissions in the NSSC process are essentially limited to particulate; however, in some cases sulfur dioxide and hydrogen sulfide may be emitted. The major sources of emissions are recovery furnaces and power boilers.

Estimated emissions in FY 1971 were 473 metric tons of particulates. Estimates for FY 1979 , with controls, is 40 metric tons.

The expected total annualized cost of control for all NSSC plants will be $10.3 million, while the total control investment for FY 1971-1979 is expected to be $26.7 million.

Industry Structure

Characteristics of the Firms. The size distribution of NSSC pulp mills is classified into three size ranges: 0-181, 182-363, and 364-635 air dried metric tons (ADMT) of air dried pulp per day. The number of plants in each size range are

Capacity Range, ADMT/day	Number of Mills	Capacity, ADMT/day	Average Mill Capacity, ADMT/day	Model Mill Capacity, ADMT/day
0 - 181	21	2,283	109	113
182 - 363	22	5,005	228	227
364 - 635	7	3,097	442	454
Total	50	10,385		

Sources: Paper, Paperboard, Wood Pulp Capacity 1971-1974, American Paper Institute; List of U.S. Pulp Mills as of December, 1972, American Paper Institute; Hendrickson, E.R., Roberson, J.E., and Koogler, J.B., "Control of Atmospheric Emissions in the Wood Pulping Industry", PB-190352, Environmental Engineering, Inc. and J.E. Sirrine Company, March 15, 1970.

Current Capacity and Projection. According to an American Paper Institute report the capacity of the NSSC mill estimated as of July 1, 1973 is 10,385 ADMT/day or 3,611,000 ADMT/year. It is estimated that the capacity growth rate from 1968 to date was about 4.75 percent/year uncompounded, and the same growth rate will be maintained until 1979. Thus, the capacities for the years of 1971, 1975, and 1979 are estimated as 3,268,000 ADMT/year, 3,954,000 ADMT/year, and 4,640,000 ADMT/year, respectively.

Emission Sources and Pollutants

For this report, discussions and calculations of air emissions from the NSSC process will be limited to particulate; the sulfur dioxide emission is relatively insignificant compared with those from other chemical pulping processes as shown in the following tabulation.

Plant	Particulate, lb/ADMT	SO_2 lb/ADMT
Digester	0	0.854
SO_2 Absorber	0	0.326
Evaporator	0	0.5
Recovery Furnace	26.6	29.2
Power Boiler	292	128
Total	318.6	158.88

The sources include the recovery furnace and power boilers. Black liquors generated in the NSSC pulping process generally are discharged to sewers although in some cases the black liquor is evaporated and cross-recovered with an adjacent kraft mill or treated in a fluidized bed system. In this study it is assumed that all the black liquors will be recovered in some manner. Coal and bark burning power boilers emit particulates as shown in the kraft mill.

The rates of emission particulates are estimated 27 lb/ADMT* and 292 lb/ADMT** from the recovery furnace and power boilers, respectively. The portion of coal used in the power boiler will influence the amount of particulate emission as shown in the kraft mill; the more the coal fraction fired, the greater the emission.

The emissions (in 1000 metric tons per year) from NSSC pulping operations over the period FY 1971 to FY 1979 are as follows:

Fiscal Year	Mode	Particulates
1971	Without Further Control	473
1975	Without Further Control	572
	With Further Control	34
1979	Without Further Control	671
	With Further Control	40

Control Technology

Control systems for particulate emission from the recovery furnace and power boilers are similar to those for kraft mills. Since the particulate emission per metric ton of air dried pulp is relatively small from the recovery furnace, a single electrostatic precipitator would provide sufficient control to meet the Washington-Oregon regulations. The annual operating efficiency is estimated as 95 percent and about 70 percent of the existing NSSC industry is to be equipped with the control device (It is estimated that about 30 percent of the NSSC industry has been equipped with a similar control system already.).

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* The black liquor resulting from the NSSC pulping process is assumed to be concentrated and burned in a recovery furnace. Particulates emission from the furnace is assumed to be 27 lb/ADMT.

** Thermal energy required to generate power for pulping process = 4.3×10^{7} Btu/ADMT. It is assumed that 70 percent of the energy is provided by coal and the rest by bark.
Coal to be burned = 1.1 ton/ADMT
Bark to be burned = 1.4 ton/ADMT
Particulate emission factor for burning coal = 230 lb/ton coal (Ash content of coal, 14.4 percent).
Particulate emission factor for burning bark = 27.5 lb/ton bark
Particulate emission from power boiler = 292 lb/ADMT

Electrostatic precipitators are not adequate to control particulate emissions from the power boilers as discussed in the section of this report on kraft mills. A cyclonic scrubber in series with an existing mechanical dust collector is needed to meet the Federal emission standard. The operating efficiency would be about 94 percent.

Control methods for the new plants were selected to meet the new source performance standards. An electrostatic precipitator and a cyclone collector plus cyclonic scrubber will be employed for the recovery furnace and power boilers, respectively. All new plants are assumed to be in the 364 to 635 ADMT/day plant capacity range.

Control Costs

The control systems employed for particulate emissions from the recovery system and power boilers are an electrostatic precipitator and a cyclonic scrubber in series with a mechanical dust collector such as cyclone. The cost data are not available with specific reference to the NSSC process. The data, however, can be estimated from the information on similar control systems used in the kraft mills.

The summary of the estimated direct costs of control for the period FY 1971 through FY 1979 is as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	21.5	18.5	24.7
Annual Costs			
Capital Charges	2.8	2.4	3.3
Operating and Maintenance	6.8	5.8	7.9
Total Annual Costs	9.6	8.2	11.2
Cash Requirements	65.7	60.4	72.8
New Facilities			
Investment	5.2	4.2	6.5
Annual Costs			
Capital Charges	0.8	0.7	1.0
Operating and Maintenance	1.9	1.6	2.3
Total Annual Costs	2.7	2.3	3.3
Cash Requirements	12.7	10.8	14.9

V. FOSSIL FUEL BURNING SOURCES

STEAM ELECTRIC POWER PLANTS

Introduction

Among the largest stationary sources of air pollution are the burners of the fossil fuels: coal, oil, and natural gas. The most significant pollutants emitted from these sources are particulate matter and the oxides of sulfur and nitrogen. Coal is the most polluting fuel among the three; natural gas is the cleanest and most convenient to use. The principal uses for these fuels include (1) electricity generation in steam electric power plants, (2) steam generation, and space heating in the industrial and commercial sector, and (3) space heating in the residential sector. In 1972, more than 82 percent of the steam coal (in contrast to coking coal) produced was used for power generation. About 63 percent of all residual fuel oil consumed and 18 percent of natural gas produced were used for the same purpose. It is apparent from these estimates that utility burners are the major sources of emission for the pollutants of concern, since they burn the most polluting fuels in the largest quantities. largest quantities.

Reduction of emissions from utility fossil-fuel burners will require a major application of new technologies and an effective distribution of available fuels. Abatement schedules for pollutants from fossil-fuel burners have been drawn up by the appropriate Federal and local authorities. These regulations which are already in effect or are slated to take effect no later than July, 1975, are aimed at preserving the quality of our air environment for protection of the public health.

In this and following sections the main concern will be the abatement of emissions in the time period 1975 to 1979. The possible technologies and alternatives that may be used for abatement will be reviewed. Expected costs of these technologies and alternatives will be presented. Effort has been made to predict the cost and effectiveness of each abatement technology and alternative with the greatest possible certainty. Some predictions pertain to the availability of control technology and the magnitude of its application in the period of concern; others pertain to the types and quantities of the various fuels available in the time period under consideration (1975 to 1979). Among the alternatives available for abatement of pollutant emissions is fuel switching. This entails the burning of the less polluting fuels (low-sulfur coal, fuel oil, and natural gas) in lieu of the more polluting ones (high-sulfur coal and fuel oil). In view of recent shortages in the cleaner fuels it is anticipated that with one exception (burning low-sulfur in lieu of high-sulfur coal) this switching to the cleaner fuels is unlikely in the time period under consideration (FY 1975-FY 1979). Low-sulfur coal is the least expensive fuel currently available in quantities significant enough for consideration as an alternative fuel. The coal transportation problem is a significant one at this time; so also is the problem of rapidly increasing mine output. This implies that, contrary to earlier expectations, larger quantities of the more polluting fuels will be burned in utility boilers. Consequently, greater efforts in the development and application of pollution control technology will have to be expended.

A summary of the estimated costs of controlling emissions of particulates, sulfur oxides, and nitrogen oxides from fossil-fueled steam electric power generators in the two time periods FY 1975-FY 1979 and FY 1971-FY 1979 are as follows:

	$ Millions					
	FY 1975-FY 1979			FY 1971-FY 1979		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Investment	5,540	4,440	7,640	7,460	5,990	9,310
Annualized Costs	3,770	2,620	4,560	4,630	3,450	5,530
Cash Requirement	17,480	11,950	21,650	19,870	14,030	23,640

These estimates are based upon simplifying assumptions which are presented and discussed in the appropriate sections of this chapter.

Background: Legislative Requirements and EPA Policy

The passage of the Clean Air Act of 1963, the Air Quality Act of 1967 and the Clean Air Act Amendments of 1970 demonstrate the concern of both the public and government over the quality of the air environment. The 1970 amendments of the Clean Air Act established the Environmental Protection Agency among whose important responsibilities were (1) the determination of ambient-air-quality standards with respect to air pollutants and, (2) the approval of SIP's for existing sources of these pollutants, and (3) the promulgation of New Source Performance Standards.

Fossil-fuel burning power plants are major sources of the air pollutants: sulfur oxides, nitrogen oxides, and particulate matter. On April 30, 1971, the EPA issued national ambient air quality standards (both primary and secondary) for these three pollutants. These standards specified the maximum allowable average 3-hour, daily, and annual concentrations of each pollutant. The primary standards, to be met by May 31, 1975 (except for specific exemptions to 1977 or 1978) specify the concentrations of pollutants (in micrograms per cubic meter) which if exceeded would, to the best knowledge available at the time, result in a detrimental effect on public health. The more stringent secondary standards, defined as the levels of air quality judged necessary to protect the public from any known or anticipated adverse effects of a pollutant, are to be met within a reasonable time as specified by the Environmental Protection Agency.

In 1971 EPA required each State to submit by January 30, 1972, plans (called State Implementation Plans--SIP's) providing for the implementation, maintenance, and enforcement of the ambient-air-quality standards in each of the Air Quality Control Regions falling into each of the states. At the same time, New Source Performance Standards were issued for a number of industrial activities. Among these were fossil-fuel-burning power plants the construction (or modification) of which commenced after August 17, 1971. These standards which are shown below for new power plants were deemed attainable and necessary for the achievement of the ambient-air-quality standards:.

Pollutant	Fuel Type Gaseous	 Liquid	 Solid
	(Pounds per million Btu)		
Particulate Matter	- -	- -	- -
SO_x	- -	0.8	1.2
NO_x	0.2	0.3	0.7

The standards set forth in the SIP's which regulate emissions from utility fossil-fuel burners will explicitly apply to existing sources (plants under construction or already in operation). While, in most SIP's, these standards are somewhat less stringent than those for new sources, they nevertheless tend to approach the latter for the larger units. Most states set 1975 as the date to meet both primary and secondary standards for sulfur oxides, and many states imposed sulfur regulations that would result in air even cleaner than secondary standards.

In response to these factors, EPA has announced a "Clean Fuels Policy". The administrator of EPA and the President have both urged the states to delay implementation of emission regulations where primary, (health-related) standards are not endangered. If the states comply with this request, the limited supplies of low-sulfur coal and stack gas cleaning technology will be restricted so as to attain primary standards within the time framework mandated by the Clean Air Act. At the same time, it would be possible to use nearly all of the current U.S. coal production and avoid the serious economic impacts that have been projected. It is possible that current legislation being considered in Congress may even give EPA the authority to change overly stringent state regulations.

Discussion of Problem: Emissions from Alternative Fuels

A choice must be made among the available fuels and to provide sufficient environmental protection from their combustion products by meeting ambient-air-quality standards while generating adequate quantities of heat and power as economically as possible. In the near term, energy resources that will be consumed in large amounts are nuclear fuels with their radioactive-waste-disposal requirements, and the fossil fuels with their ash-residue-disposal and gaseous-emission-control requirements.

Among the fossil fuels, natural gas is the cleanest, but is in short supply. To demonstrate the relative cleanliness of gas relative to coal and oil the emissions resulting from the use of each fuel in a 1,000 MWe power plant is given below.

Fuel	Emissions, kilograms per hour		
	Particulates	SO_2	NO_x
Coal	31,364	18,636	5,909
Oil	273	5,682	3,909
Gas	77	3	3,091

As indicated, natural gas is the preferred fuel from an emissions standpoint. Indeed, gas-fired power plants provided 29 percent of electricity in 1971, and gas provided about one-third of all heat energy derived from fossil fuels. However, the production of gas during the near term is expected to remain fairly constant, and growth in fossil fuel demand will be taken up by coal and oil.

Despite current shortages in the U.S., petroleum is still an abundant fuel internationally. For mobile sources, its derivatives, gasoline and diesel oil, are not expected to be supplanted in the near future. For utility burners, despite the potential switch from oil to coal in many power plants, distillate and residual fuel oil will continue to supply a significant fraction of the energy required in 1980. Fuel oils for utility burners contain sulfur (typically sulfur contents average about 0.7 percent for United States crude oils and about 2.2 percent for imported crude oils). Much of this is removed from the final product. The ash from crude oil combustion is low, about 0.5 percent.

The supply of crude oil and its derivatives in the United States is becoming increasingly critical due to limited reserves of domestic sources and increasing international demand for this versatile fuel. Furthermore, oil is in most demand for electric power in areas where foreign oil was and probably will continue to be more accessible.

The most abundant fossil fuel in this country is coal. In 1971, about 327 million tons of coal were burned to supply about half of United States electric power. In 1970, 100.5 million tons were used for heating, 98 million tons were used to produce coke for use in industrial processes, and 73 million tons were exported. The resources of coal are widespread through the United States, but coal has not been used in proportion to its availability in comparison with the other fuels.

Coal typically has an ash content of 9 percent, of which (under uncontrolled conditions) about 85 percent would be emitted with a dry-bottom boiler, and 65 percent with a wet-bottom boiler. The resulting emissions would be orders of magnitude (as the tabulation shows) higher than those from the combustion of the other fossil fuels. Particulate controls of varying efficiencies are found in all but the smallest coal burners.

Sulfur dioxide emissions from coal burning are even more serious and more difficult to control. In 1970, the sulfur content of coal burned by utilities, industry, and in heating units for household and commercial use averaged 2.5 percent. This sulfur appears as sulfur dioxide and some sulfur trioxide when the coal is burned. To reduce the sulfur oxides, a coal with low-sulfur content could be chosen. However, much of the Eastern low-sulfur coal is reserved for use as coke by the metals industries. In only 6 percent of current production is the sulfur content low enough to meet New Source Performance Standards. The major Western low-sulfur coals are uneconomical to ship to power plants east of Chicago. Western coals will be used extensively in the Central Region.

In spite of these problems, use of coal to supply most electric power in the near future seems unavoidable. Sulfur dioxide emission control, therefore, will require much change from current practice. As well as switching to low-sulfur coal, other strategies are possible. These include removal of sulfur from flue gases, and removal of sulfur from high sulfur fuels before burning.

The uncontrolled and controlled emissions from utility fossil-fuel burners may be estimated from known (measured) emission factors, for the first case, and from the capability of the various control techniques in the second. Utility burners are major sources of the three pollutants; namely, the oxides of nitrogen and sulfur, and particulate matter. The 1975 controlled and uncontrolled emissions from this source are shown below in millions of metric tons.

	Uncontrolled Emissions			Controlled Emissions					
				Most Probable			Maximum That May Be Achieved		
	SO_x	NO_x	Particulates	SO_x	NO_x	Particulates	SO_x	NO_x	Particulates
Coal	22.1	7.9	34	8.6	7.5	0.5	5.4	3.2	0.5
Oil	3.2	1.6	--	2.0	1.5	--	2.0	0.7	--
Gas	--	1.2	--	--	1.1	--	--	0.4	--

The "uncontrolled emission" levels were computed from 1975 fuel-consumption data and emission factors for the various fuels. The "most probable" levels of emission represent those that may be expected after the application of the various control alternatives. Emissions labeled "maximum that may be achieved" are those that can be expected if the New Source Performance Standards are uniformly applied.

Control Technology

The New Source Performance Standards pertaining to utilities were proposed in August, 1971, after considerable effort in determining their feasibility. The performance standards represent emissions (of sulfur oxides, nitrogen oxides, and particulate matter) that may be expected following the application of the most advanced and economically feasible control technology. In principle, it is possible to drastically reduce emissions of all pollutants mentioned by switching from the more polluting fuels (coal and high sulfur oil) to the less polluting ones. The availability of less polluting or "clean" fuels is limited. Therefore, control will have to rely heavily on the installation of control equipment except as noted above. A number of alternatives and techniques which are currently available for the control of pollutants emitted from utility power plants are discussed below.

Sulfur Oxide Control

The principal means to abate the emissions of sulfur oxides are: (1) use of fuels containing less sulfur (low-sulfur coal and fuel oil); and (2) flue-gas desulfurization.

Fuel Switching. In principle, it is possible to meet all the SO_2 emission restrictions for steam electric plants by increasing the consumption of the so-called "clean" fuels (natural gas and low-sulfur coal and fuel oil) and, simultaneously decreasing the consumption of the "dirty" fuels (high-sulfur coal and residual oil). This is not only true for sulfur dioxide but also for the other two pollutants from this source; namely, nitrogen dioxide and particulates. Deterrents to massive conversion to the "clean" fuels are the problems of availability and cost. The cleaner fuels, with the exception of low-sulfur coal, are increasingly becoming in short supply. And as demand for the cleaner fuels in other uses (household and commercial) increases, their availability for power plant usage will decline. In nearly all recent projections by industry and government, an increase in the use of gas and residual fuel oil for utility purposes is foreseen. This may not be true in the case of gas, and no significant increase in fuel-oil consumption is foreseen before 1975. Many uncertainties exist about the supply/demand situation for fuel oil. Most of these uncertainties stem from political instabilities existing in the crude-oil supply sources in the Middle East, North Africa, and South America. The use of natural gas and low-sulfur fuel oil by utilities probably will not increase, and may decrease.

The total 1975 utility requirement of fuel oil (both distillate and residual) will probably be about 5300 trillion Btu's. In the absence of any sulfur regulations, about 60 percent of the oil burned will contain less than 1 percent sulfur. However, in order to meet the SIP's, more than 80 percent of the oil burned will have to contain less than 1 percent sulfur. This will call for added fuel desulfurization at the refinery level. The technology for the accomplishment of this added desulfurization is available. It is uncertain whether enough desulfurization capacity can be constructed by 1975.

For some coal-burning plants in the Midwestern states, low-sulfur coal is an economic alternative for meeting sulfur dioxide regulations. Switching to low-sulfur fuel oil is not a viable alternative in view of current shortages. In the contiguous U.S., low-sulfur coal of sulfur content less than 1.0 percent is found in significant quantities in the Appalachian region (Western Virginia and Eastern West Virginia and Kentucky), and in the western states: North Dakota, Montana, Wyoming, Colorado, and Utah. First, the Appalachian low-sulfur coal will not be available in significant amounts for Eastern and Central utilities for a number of reasons. Among others, the supplies of this coal are insufficient for meeting long-term utility requirements in the Eastern half of the U.S. Strippable reserves of low-sulfur coal amount to only 850 million tons, whereas reserves obtainable from deep-mining operations are about 750 million tons. The total reserves represent less than three times the 1972 utility demand in the Central and Eastern regions. Second, for most Eastern utilities, high-sulfur coal used in conjunction with flue-gas desulfurization (FGD) to meet sulfur oxide regulations will be cheaper than using Eastern low-sulfur coal. For central utilities it is cheaper to use high-sulfur coal in conjunction with FGD or Western low-sulfur coal.

Subbituminous coals (with heating values of about 8500 Btu/lb) and lignite (6500 Btu/lb) of low-sulfur content (0.7 percent or less) are found in large quantities in a number of Western states. Lignite deposits are found in North and South Dakota and Montana, while subbituminous coals are found in a discontinuous belt across easter Montana, Wyoming, and Colorado. The recoverable reserves of the subbituminous coals are estimated at 150 billion tons. Some of the properties of lignite pose serious problems in transportation. The high moisture content (about 30 percent) gives rise to freezing problems. It is also subject to spontaneous ignition. Therefore, only the subbituminous Western coals may be considered for export to the Eastern half of the U. S. Lignite will probably be utilized in minemouth power plants.

Western coal production in Montana, Wyoming, and the Dakotas amounted to about 16 million tons in 1972. It is estimated that an additional 30 million tons could be available by 1975 from this source. The demand for Western low-sulfur coal will continue to increase between 1975 and 1980. Probably more than 90 percent of this will be exported to utilities located in the Midwest.

There are a number of problems associated with the use of Western low-sulfur coal in Central and Eastern utilities. Transportation over long distances may triple the costs per ton. Rail capacity will have to be expanded. Wet-bottom boilers, designed for burning high-sulfur coal with a low ash-fusion temperature, account for a substantial percentage of the generating capacity in the Central and Eastern regions (perhaps more than 18 percent). Since Western low-sulfur coal has a high ash-fusion temperature, costly and time-consuming boiler modifications will have to be undertaken by the utilities in the Eastern and Central regions. It is not clear at this time whether all necessary conversions will be made by 1975. For these reasons, the use of Western coal will probably be limited to existing Central utilities with dry-bottom boilers and for new utilities in the Central Region.

Flue Gas Desulfurization (FGD). There are more than 50 processes which have been proposed for the removal of sulfur oxides from stack gases. In many of these processes flue gas containing sulfur oxide is contacted in a suitable device with an aqueous solution (or slurry) containing an alkaline material which reacts with the sulfur oxides. Depending on the type of treatment the alkaline solution receives after the contacting operation, a desulfurization process may be either regnerative or throw-away. In a typical regenerative process the absorbing solution containing the sulfur oxides is treated in such a way as to obtain the sulfur oxides (as SO_2) in a more concentrated form than as originally found in the flue gas. A number of options are currently available for conversion of SO_2 in this concentrated gas stream. It can be converted to elemental sulfur on the one hand or to sulfuric acid on the other. In the throwaway-type process, the sulfur oxides react with the alkali to form the relatively insoluble sulfates and sulfites of, mainly, calcium. These have been disposed of in the form of a wet sludge.

A number of FGD processes have achieved prominence as a result of relatively extensive testing in actual and comparatively large pilot-scale operations. Three of these processes are of the throwaway type. These processes are (1) lime scrubbing, (2) wet limestone scrubbing, and (3) double alkali process. The alkalis used in the first and second processes are lime and limestone, respectively, whereas soda ash is used in the third process. Lime is used to regenerate the soda ash.

There are three prominent regenerative FGD processes. In the first process, a slurry of magnesia is used to absorb the sulfur oxides. The sulfites and sulfates of magnesium result from the reaction. Regeneration of these to magnesia is carried out by calcination of the dewatered slurry with small amounts of coke (used to reduce the sulfate). Sulfur dioxide in high concentration is liberated in the calcination process. The sulfur dioxide is subsequently converted to sulfuric acid. In another process sodium sulfite is used as absorbent. The main product of reaction is the bisulfite of sodium. Stripping with steam releases the absorbed sulfur dioxide which can be converted to elemental sulfur or sulfuric acid. A relatively small but significant amount of sulfate is formed in the process. This is continuously purged along with the associated sulfite. Alternatives for the proper ultimate disposal of this purge stream are currently under scrutiny.

In yet another process, the sulfur oxides are catalytically oxidized to sulfur trioxide prior to absorption in dilute sulfuric acid. The product acid (of about 80 percent concentration) may find uses in various chemical processes or may be neutralized with limestone if market conditions are such that sale of the product is not possible.

All of the FGD processes mentioned above are capable of reducing sulfur oxide emissions by at least 80 to 85 percent. Their use will make possible the burning of high-sulfur fuels (coal and oil) without exceeding the standards set forth in the SIP's as well as in the New Source Performance Standards for power plants. However, some technical and environmental problems will result from widespread application of these processes.

In some of these processes (especially the throwaway types) undesirable by-products in the form of sludges or alkaline salt solutions are obtained. As a result of the recent public hearings on the status of FGD technology, EPA has concluded that technology has been recently developed to reclaim sludges for use as stable landfills. In these cases when landfill is not applicable, regenerative FGD processes should be considered.

In some other processes, operational and reliability problems may result from improper design, construction, or monitoring thereof. (It seems that many of the problems encountered in the pilot testing of the various processes might be adequately solved in the time period between 1974 and 1979). It is predicted that the period 1975 to 1980 will see a widespread application of FGD systems. Perhaps more than 100,000 MW of generating capacity will utilize FGD systems for sulfur oxide control in 1979. This would amount to about 20 percent of the total fossil steam electric generating capacity.* It is noteworthy that the cumulative capacity for manufacturing and installing FGD systems by 1979 has been estimated but at twice that required by the above demand estimate.*

Other Options. Tall stacks and intermittent control systems are two alternative control systems which can be used to take advantage of the dispersion characteristics of the atmosphere to avoid heavy ambient concentrations. Tall stacks emit pollutant streams at high enough altitudes that they disperse before reaching ground levels. Intermittent control systems use meteorological data and air-quality measurements to determine when high emission rates will not threaten air-quality standards. Thus, in an intermittent system a plant would use high-sulfur fuels or high operating rates at times when the air is clean and there is good dispersion of pollutants, but at times of dirty air or poor dispersion it would switch to low-sulfur fuels, low operating rates, or (for certain types of facilities) even shut down.

Such operation has the advantage of allowing maintenance of air quality standards at much lower expense than by use of low sulfur fuels or stack gas cleaning equipment. It has the disadvantage however of allowing higher levels of emissions of sulfur oxides which yield high exposure to the health effects of sulfates, which are formed by atmospheric conversion of sulfur oxides. Higher sulfur oxide levels also yield higher property damages due to acid rains. It is a difficult tradeoff to make between substantially lower costs to achieve sulfur oxides standards and higher risks of damages from total atmospheric loading of sulfur oxides. EPA's current posture on tall stacks and intermittent control systems has been to allow them only as an interim measure. In September, 1973 EPA proposed regulations that limit use of dispersion techniques to situations where permanent controls are not available (such as where there is not room to install a scrubber), and where the alternatives are a permanent production curtailment, a shut down, or violation of air quality standards. It is expected that these interim alternatives will be of greatest use for coal-fired power plants and copper smelters.

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* EPA estimates 90,000 MW of generating capacity will utilize FGD systems as spelled out in the recently issued National Public Hearings on Power Plant Compliance with Sulfur Oxide Air Pollution Regulations, U. S. EPA, January, 1974.

In the early 1980's, coal-refining technology will probably make a significant contribution to the supply of clean fuels available at that time. Two prominent types of coal-refining processes are noteworthy. In the first, coal is converted at high temperatures and pressures, and in the presence of air and steam to a pipeline-quality (sulfur free) fuel gas similar in characteristics to the well-known natural gas. The other type of coal refining involves the removal of the impurities (sulfur and ash) by the simultaneous dissolution and hydrogenation of the coal at high temperatures and pressures. The ash is separated from the coal solution in a suitable device. The organic sulfur in the coal is converted to hydrogen sulfide gas (by hydrogenation) and the inorganic sulfur is associated with ash.

Many other direct and indirect alternatives will become available for sulfur oxide abatement in the last two decades of the Twentieth Century. As energy sources other than fossil fuels gain wide application and chemical conversion processes for refining the "dirty" fossil fuels become commercially available, the significance of the sulfur oxide problem will be greatly diminished. The still-untapped solar, geothermal, and tidal energy sources may foreseeably become sole sources in the future. Such novel sources of energy as thermonuclear fusion, fast-breeder reactors may sometime in the future supplant the use of fossil fuels.

Nitrogen Oxide Control

The present state of the art for control of emissions of nitrogen oxides from utility boilers calls for techniques that involve modification of the combustion process. In general, they follow schemes that were originally developed for NO_x control in natural-gas-burning equipment. Combustion modification involves reducing temperature in the furnace and promoting conditions that prevent the oxidation of fuel-bound nitrogen (in coal and oil only). Fuel switching (mainly to natural gas) may be considered a possible alternative in cases of adequate fuel availability.

With regard to the control of nitrogen oxides emission from steam electric power stations, two cases have been encompassed. In Case 1, the cost of controlling all nitrogen oxides has been estimated.

The need for absolute and uniform control appears to be unnecessary. In the period FY 1975 to FY 1979, it is expected that nitrogen oxides emissions control will be required only in the Los Angeles area (AQCR 24) and in the Chicago area (AQCR 67). Costs of nitrogen oxides control were estimated for Los Angeles and Chicago as Case 2. In FY 1975, the estimated electric generating capacity for Los Angeles is 11,770 MW, fired by oil and gas. In the same year the Chicago AQCR is estimated to include 7,700 MW of coal-fired, and 7,000 MW of oil/gas fired generating capacity.

Coal. The applicability and effectiveness of NO_x control in coal burners is largely affected by the type of burner employed, and perhaps to a lesser degree, the sulfur content and rank of the coal. On the basis of the total heat duty of all utility boilers, it is estimated that 85 percent are fed pulverized coal. The balance thereof (15 percent) are fitted with cyclone burners requiring crushed (chunk) coal. Three types of pulverized coal-fired furnaces are found. These are: (1) the tangentially fired, (2) the dry ash type, and (3) slag-tap (wet bottom). It is estimated that these three types make up 50, 33, and 2 percent of all utility coal-fired boilers, respectively.

In general, the combustion modification techniques des- described below apply only to the dry-bottom furnaces. The wet-bottom boilers (cyclone and pulverized-coal slag-tap) will have to be retrofitted to the dry-ash pulverized-coal variety before NO_x control by combustion modification is applied, although switching to oil or gas firing would eliminate the retrofit problem.

The NO_x control techniques that may be applied to coal-fired boilers are: (1) low (or minimum) excess air firing, (2) staged combustion and off-stoichiometric firing, (3) flue-gas recirculation, (4) water injection, and (5) fuel switching. In the first technique, the amount of air above stoichiometric that is introduced to the burner is kept to a minimum. NO_x reductions of 50 percent have been experienced with this technique in a tangentially fired boiler. Staged combustion and off-stoichiometric firing involves running some or all burners rich in fuel the introducing the balance of the air through either NO ports (usually located above the burners) or through the fuel-lean burners if the latter alternative is chosen. This technique offered a reduction of 60 percent in tangentially fired boilers. The third technique involves flue-gas recirculation whereby a portion of the coal combustion products is diverted back to the windbox. Despite a lack of experience with this technique with large-scale boilers, it is expected to yield similar reductions as those obtained in oil firing. The fourth technique involves the injection of water into the burner. This has the effect of reducing flame temperatures with simultaneous reduction in the thermal efficiency. The fifth alternative involves the switching to oil or gas firing since flame temperatures and fuel nitrogen are lower for these than for coal.

It is apparent from the above that staged combustion and off-stoichiometric firing is the most suitable method for controlling NO_x emissions from coal burners. Not only does it give the highest percentage reduction of NO_x of the most probable techniques, (1) through (4), but also does not result in derating the boiler (as in water injection). Fuel nitrogen is prevented from being oxidized because of the reducing atmosphere occurring in the early stages of combustion.

Oil. The techniques described for control of NO_x from coal-firing are generally applicable to those originating from oil firing. By the same reasoning (given for coal in the previous paragraph) staged combustion and off-stoichiometric firing will be used to control NO_x emissions. The reduction in NO_x obtained may be as high as 55 percent.

Gas. NO_x control in gas-fired boilers may be achieved with either flue-gas recirculation or staged combustion and off-stoichiometric firing. However, the latter technique seems to have lower annual and investment costs. Reductions in NO_x up to 70 percent NO_x may be expected.

Particulates Control

Particulate control would normally be undertaken in all coal-fired utility boilers. In most cases, particulate control is not necessary for fuel oil-fired boilers. The uncontrolled emissions of particulates from coal burning boilers are usually 50 to 100 times higher than those from oil burning on a per million Btu basis. Except in soot blowing operations, fuel oil firing will meet the standards set in the SIP's when burners are kept at peak efficiency. This also applies to natural gas burners.

Coal-fired boilers are mostly of two types. The first, accounting for about 83 percent of steam generated electrically (from coal) are of the dry-bottom type utilizing pulverized coal. The remainder of the steam-electricity from coal is obtained from wet-bottom boilers. The uncontrolled particulate emissions from dry-bottom boilers are about 80 percent of the ash contained in the coal charged. For wet-bottom boilers (mainly of the cyclone variety) those uncontrolled emissions are about 30 percent of the ash in coal.

Particulate control may be achieved by either wet or dry methods. In the wet systems, the flue gas is scrubbed with water in a suitable contacting device. The ash-laden scrub water is then sent to a thickener wherein suspended solids content is increased to about 30 percent. The clear effluent from the thickener is recycled to the scrubber whereas the stream containing most of the ash is neutralized with limestone (or lime) before disposal in a pond. Neutralization is necessary since about 20 percent of the SO_2 in the flue gas is absorbed in the scrub water. The particulate overall removal efficiency by this method may be as high as 99.9 percent. Dry methods of particulate removal may be divided into (1) mechanical and (2) electrostatic. Mechanical methods include passing the ash-laden flue gas through such devices as cyclones and baghouses. In cyclones the gas-solid separation is achieved by the development of a centrifugal force on the ash particle, inside the device, thereby inducing it to move away from the main gas stream into a compartment where solids accumulate. The baghouse is a particulate-removal device in which the particulate matter is removed by passing the gas through a fabric filter in the form of a number of cylindrical bags. The dust collects on the inside surfaces of the bags and is continuously removed by mechanical shaking of the bags along the cylindrical axis. In electrostatic separation, the gas is subjected to a high-strength electric field between two electrodes. A corona discharge (a process by which gas molecules are ionized) between the electrodes causes the solid particles to become charged. These charged particles are subsequently attracted by collector electrodes which in turn are periodically trapped to remove deposits. The collection efficiency of all dry systems described above is 99 percent or better with the exception of cyclones where it is about 80 percent only.

The technique to be used in any particular situation depends largely on (1) the type of coal burned, (2) its sulfur content, (3) availability of space and adequate water supplies and (4) the percentage removal required by applicable standards. It has been found that SO_2 in the flue gas tends to decrease the resistivity of the ash particle in the electric field between the electrodes in an electrostatic precipitator. This results in faster and more efficient collection of the ash particles. Roughly twice as much collector area is needed to collect the same amount of flue gas resulting from the burning of 1 percent sulfur coal as compared to a coal containing 2 percent sulfur. This effect of the sulfur content of the coal is diminished by lowering or raising the temperature about 300 F. In cases where there are space limitations and retrofit problems are difficult, wet scrubbing in a high-energy venturi (as explained under wet methods) may be used for low-sulfur coal. This is probably the case for existing units without adequate particulate controls although baghouses may be also applied with equal efficiency.

Prior to the promulgation of the Clean Air Act of 1970, perhaps 95 percent of all coal-burning power plants had particulate-removal equipment, of varying efficiency, installed. The range of the removal efficiency may have been between 40 and 90 percent. For purposes of this study, it was estimated that by 1970, 75 percent of all coal-burning electricity generators (on a kilowatt basis) had particulate control of about 90 percent efficiency. Of course, most SIP's call for about 99 percent reduction in particulates. As a result, most existing (1970) control equipment could not meet the standards for particulates without complete replacement or substantial additions. In the case of electrostatic precipitators, going from an efficiency of 90 to 99 percent will require a doubling of the size of the unit. This is a significant increase in cost as well as in size.

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Control Costs

The cost estimates of air pollution control developed in this section apply to investments and operating and total annual expenditures, in 1973 dollars, incurred by utilities in the periods 1970 to 1975 and 1975 to 1979 as a result of the passage of the amendments of the Clean Air Act of 1970. The air pollutants to be abated are the oxides of sulfur and nitrogen and particulate matter. The cost estimates were based on projections of the sulfur content and total fossil-fuel consumption in the period 1970 to 1980. With the exception of natural gas, for which no growth in consumption was assumed, a significant growth in the utilization of oil and coal was predicted. Where oil consumption may decline in 1974, an upward trend will continue through 1980. Coal utilization will steadily grow through 1980 with a growth rate increasing as utilities decrease the relative proportions of oil and natural gas fuels consumption. The annual fossil-fuel consumption (in trillion Btu) by utilities for the period 1970 to 1979 is given below.

	1970	1975	1979
Coal[a]	7,400	10,500	13,000
Oil[a]	3,000	5,700	7,800
Gas[b]	4,000	4,000	4,000

(a) EPA data derived prior to the energy crisis.
(b) Assuming no growth over 1971 consumption.

Sulfur Oxide Control Costs

The costs were developed for both coal- and residual (and distillate)-fuel-oil burning utilities. Of course, the sulfur content of natural gas is negligible for purposes of this study.

Three alternatives were considered for reducing sulfur oxide emissions from coal-burning utilities. These were, (1) flue gas desulfurization (FGD), (2) switching from high- to low-sulfur coal and (3) switching from coal to low-sulfur residual fuel oil.

While flue-gas desulfurization systems will be applied mostly to coal-burning utilities, some will be applied to high-sulfur-oil burning systems. The EPA believes that investment costs for these systems will probably fall in the range of \$30 to \$65 per kw depending on whether they are applied to new or existing plants. Some experts prefer a range of \$50 to \$85 per kw; in this work, the EPA estimate has been used. Depreciation of the investment was carried over a period of 7 years. Generating capacities of 1000, 7000, 50,000, and 93,000 Mw were assumed to have FGD systems installed in mid-1972, 1975, 1977, and 1979, respectively. The estimated costs of control of SO_x emissions by FGD systems in the period FY 1971 through FY 1974 and for the period FY 1975 through FY 1979 (\$ Millions) are presented in the tabulations on the following page.

Many Central and Eastern utilities burning high-sulfur coal may elect to switch to low-sulfur coal from the Western states. The 1973 minemouth cost of Western low-sulfur coal was about 21¢ per million Btu. Transportation to the Chicago area will add about 40¢ per million Btu to the cost of this coal. In general, it may be stated that the overall cost of this fuel will be competitive in many instances with the cost of using Central high-sulfur coal in conjunction with FGD. It is projected that 1560, 1720, and 1810 trillion Btu's of low-sulfur coal will be burned in utility boilers in the years 1972, 1975, and 1980, respectively. Since most of this low-sulfur coal will be burned in lieu of Central high-sulfur coal, an investment cost attributable to boiler conversion was included for the period 1975 to 1979.

Based on previous projections of the cost and availability of low-sulfur residual fuel oil, a portion of the 1975 coal-fired capacity (estimated at 12,500 Mw) had planned to switch to low-sulfur oil by 1975. Investment costs for boiler conversion would amount to \$20 per kw. A 20¢ to 30¢ per million Btu increment in fuel cost should be expected. However, in view of the current oil embargo by some of the oil-producing countries, it is unlikely that any additional coal-fired plants will switch to oil. In fact, a significant number of power plants will probably switch from oil to coal which will result in both conversion costs and in costs for SO_x control.

Nitrogen Oxide Control Costs

It was found that staged combustion and off-stoichiometric firing is adequate for controlling NO_x from all fossil-fuel utility burners. The costs of modifying "new" boilers are about 56¢ per kw for oil and gas burners and \$2.25 per kw for coal burners. These costs are 35 percent higher for "existing" units. Operating and maintenance costs may amount to 2 percent of the investment costs per year.

Costs of NO_x control have been estimated for two cases. For Case 1, the estimated cost for controlling NO_x emissions from all steam electric power generation sources in the period FY 1975-FY 1979 is

The estimated costs of control of SO_x emissions by FGD systems in the period FY 1971 through FY 1974 ($ Millions) are as follows:

Fuel	Sulfur Oxide Control Technique	Investment			Annual Operating and Maintenance			Annualized Costs			Total Period Cash Requirements		
		Avg	Low	High	Avg	Low	High	Avg	Low	High	Avg	Low	High
Coal	Flue gas desulfurization	403	350	455	37	29	44	129	110	144	480	414	545
Coal	Switch to low-sulfur coal[a]	--	--	--	530	530	675	530	530	675	530	530	675
Oil	Switch to low-sulfur oil[b]	--	--	--	200	200	260	200	200	260	200	200	260
	Totals	403	350	455	767	759	979	859	840	1084	1210	1144	1480

(a) Represents fuel cost only.
(b) Fuel desulfurization cost (only).

The estimated costs of control of SO_x emissions by FGD in the period FY 1975 through FY 1979 ($ Millions) are as follows:

Fuel	Sulfur Oxide Control Technique	Total Period Investment			Annual Operating and Maintenance Costs			Total Annualized Costs			Cash Requirement for Period		
		expected	min	max	expected	min	max	expected	min	max	expected	min	max
Coal	Flue gas desulfurization	4,035	3,150	4,920	676	540	810	1,690	1,340	2,050	7,140	5,620	8,660
Coal	Switch to low-sulfur coal	1,470	1,250	1,910	1,090	560	1,150	1,260	710	1,370	6,210	3,500	6,750
Oil	Fuel Desulfurization	--	--	--	507	310	630	507	310	630	2,540	1,550	3,150
		5,505	4,400	6,830	2,273	1,410	2,590	3,460	2,360	4,050	15,890	10,670	18,560

presented in the following tabulation:

Fuel	Total Investment	Annual Operating and Maintenance	Annualized Costs	Cash Requirement
	Expected Cost (Case 1), $ Millions			
Coal	658	13.2	90.5	890
Oil	94	1.9	12.9	127
Gas	56	1.1	7.6	75
	808	16.2	111.0	1,092

These estimates for Case 1 are the basis for the maximum level of nitrogen oxides emission control.

For Case 2, the estimated costs for controlling NO_x emissions only from sources in Los Angeles (AQCR 24) and Chicago (AQCR 67) during the period FY 1975-FY 1979 are as follows:

Fuel	Total Investment	Annual Operating and Maintenance	Annualized Costs	Cash Requirement
	Expected Cost (Case 2), $ Millions			
Coal	10.8	0.2	1.5	14.6
Oil/gas	26.2	0.6	3.6	35.6
	37.0	0.8	5.1	50.2

These estimates for Case 2 are the basis for both the expected and the minimum levels of nitrogen oxides control.

Particulate Controls Costs

The costs of both wet and dry techniques of particulate removal were obtained. The investment and operating costs of wet scrubbing were typically $14.5 and $2.2 per kw per year, respectively, including stack-gas reheat. The investment and operating costs of dry removal by electrostatic precipitation were typically $10.8 and $0.3 per kw per year, respectively. Only coal-burning utilities will require particulate control.

In obtaining the costs of control it was assumed that 75 percent of the 1970 generating capacity that requires particulate control will have electrostatic precipitators of 90 percent efficiency already installed. This efficiency will be gradually upgraded to 99 percent by 1975. The other 25 percent of FY 1971 capacity was assumed to require wet scrubbers the installation of which will be complete by mid FY-1975. Controls for new capacity coming on stream between FY 1975 and FY 1979 were installed immediately. For this new capacity, it was assumed that 50 percent will be controlled by wet scrubbing, the balance being controlled by electrostatic precipitators. The expected costs for particulates controls for coal-burning stationary sources for the three time periods of interest are as follows:

Period	$ Millions (Expected Values)			
Period	Investment	Annual Operating and Maintenance	Annualized Costs	Cash Requirement
FY 1971-FY 1974	1,550	76	195	780
FY 1975-FY 1979	--	122	308	1,540
FY 1971-FY 1979	1,550	122	308	2,770

The best available information on the possible accuracy of these estimates suggests an error band of plus 30 and minus 20 percent about the expected values given in the tabulation above. This error band has been assumed in presenting the summary tabulation in the Introduction to Chapter V.

COMMERCIAL, INDUSTRIAL, AND RESIDENTIAL HEATING

Introduction and Summary

Nature of the Products and Processes

Boilers and furnaces utilized in commercial, industrial, and residential heating contribute to air pollution by the release of a variety of pollutants as products of fossil-fuel combustion. These pollutants include particulate, carbon monoxide, sulfur oxides, nitrogen oxides, and hydrocarbons. The level of these pollutants emitted are dependent upon the design and operation of the boiler and on the type of fuel fired. Assuming proper design and operation of the boiler, fuel becomes the most significant variable affecting emission levels.

The majority of commercial and industrial heating is accomplished by hot water and steam boilers. Although hot air furnaces are utilized for space heating, these units are fired on gas or distillate oil and generally are not major contributors to the pollution problem. Essentially all residential heating is accomplished by hot water boilers and hot air furnaces that burn either distillate oil or natural gas. There are a few coal-fired residential furnaces, but the number is insignificant and can be ignored.

Emissions and Control Costs

Of the pollutants mentioned above, only particulates and sulfur oxides emissions generated by commercial and industrial coal-fired boilers, require control technologies to reduce levels to comply with regulations established pursuant to the Clean Air Act Amendments of 1970. Less than 25 percent of the current residual oil consumed has a sulfur content above equivalent permissible SO_2 levels. Switching to a low-sulfur oil will reduce SO_2 levels to within regulations with essentially no costs involved other than the slightly higher cost of fuel. Because of the current fuel shortage and the resulting instability in fuel prices, no attempt was made to account for cost differential between high- and low-sulfur residual oil and coal. It is judged that these fuel costs on a consistent basis will tend to become virtually equivalent. Presently, there are no nitrogen oxides emissions regulations for boilers in commercial and industrial heating applications.

In addition, there are no air pollution regulations for boilers and furnaces in the residential heating application; neither is there any suitable control technology. Although fuel switching from coal to one of the cleaner fuels could be considered a control, only a small percentage of the existing residential heating units fire coal. Conversion of these units to a clean fuel would have an insignificant effect on the total emissions from residential heating. For these reasons, control costs for residential heating are not presented in this report.

Particulate emissions for commercial, industrial, and residential heating are estimated to have been 8.4 million metric tons in FY 1971. Particulate emissions with additional controls are estimated to be 1.1 million metric tons in FY 1971. Sulfur oxides emissions for commercial, industrial, and residential heating are estimated to have been 8.5 million metric tons in FY 1971. Sulfur oxides emissions with additional controls (which meet limits established in the SIP's) are estimated to be 7.5 million metric tons in FY 1979.

The estimated total investment and annualized control costs for commercial, industrial, and residential heating between FY 1971 and FY 1979 are $4.1 billion and $1.1 billion, respectively.

Industry Structure

Characteristics

Commercial equipment normally is defined as equipment having capacity in the range 0.05 to 2.11 million kg cal per hour. Industrial equipment normally is defined as equipment having capacity in the range 2.11 to 169 million kg cal per hour. Residential equipment is defined as equipment used in residences and individual apartments. Capacities of residential boilers and furnaces are typically less than 0.075 kg cal per hour, but could be higher depending upon the size of residence to be heated. These ranges are loosely defined and in practice often overlap. The equipment size distribution by location and fuel type is not availble.

Current Capacity and Growth Projection

The estimated 1973 installed capacity of commercial and industrial boilers is 10 x 10^{15} kg cal per year (approximately equivalent to 1.6 billion metric tons coal per year) based upon a 1967 inventory and assumed growth rates of 4.5 percent per year for commercial units and 4 percent per year for industrial units. The growth rate for commercial and industrial boiler capacity is estimated to be 3 percent per year. It is estimated that residential boilers and furnaces consumed the energy equivalent of 1510 x 10^{12} kg cal in 1973, of which 53 percent was natural gasaand 47 percent was distillate oil. An insigificant amount of coal was consumed for residential heating. The growth rate for residential units is estimated to be 1.1 percent per year.

The current estimated capacity for coal-fired boilers is 770 million kg per hour, with an estimated growth rate of 7 percent per year. This substantial increase in growth rate of coal-fired boilers has been assumed because of the current shortage of natural gas and oil.

Emission Sources and Pollutants

Pollutants emitted by fossil-fuel combustion are a function of fuel composition, efficiency of combustion, and the specific combustion equipment being used. Particulate levels are related to the ash content of the fuel. Sulfur oxides levels are related to the sulfur content of the fuel. Emissions of nitrogen oxides result not only from the high temperature reaction of atmospheric nitrogen and oxygen in the combustion zone, but also from partial combustion of the nitrogenous compounds contained in the fuel; thus, levels are dependent both on combustion equipment design and upon fuel nitrogen. Carbon monoxide, hydrocarbon, and particulate levels are dependent on the efficiency of combustion as it is affected by combustion equipment design and operation. Accordingly, natural gas and distillate oil are considered clean fuels because of their low ash and sulfur contents, and also because they are relatively easy to burn. In contrast, coal (and some residual oils) contain significant amounts of sulfur and ash, require more sophisticated combustion equipment and are more difficult to burn than the clean fuels.

The estimated uncontrolled emission factors and average emission factors required by the state implementation plans (SIP) for commercial, industrial, and residential boilers are listed below based on the following assumptions and conditions:

- The sulfur contents of coal, residual oil, and distillate oil are assumed to be 3, 2, and 0.2 percent by weight, respectively.
- The ash content of coal is assumed to be 12 percent by weight.
- The difference in particulate emissions factors between commercial and industrial coal-burning installations probably is related to differences in equipment design.

In the following tabulation of emissions factors (in kg per million kg cal) parenthesis indicate factors required or allowed by SIP, where applicable:

	Emission Factors, kg per million kg cal				
	Particulates	Sulfur Oxides	Nitrogen Oxides	Carbon Monoxide	Hydrocarbons
Commercial					
Coal	1.8 (1.08)	8.6 (5.8)	0.45	0.76	0.23
Residual Oil	0.29 (1.08)	4.0 (2.0)	0.74	0.050	0.038
Distillate Oil	0.18 (1.08)	0.36 (0.43)	0.74	0.050	0.038
Gas	0.032 (1.08)	0.0011	0.17	0.034	0.014
Industrial					
Coal	11.7 (0.63)	8.6 (5.7)	1.13 (1.26)	1.5	0.076
Residual Oil	0.29 (0.63)	4.0 (2.0)	0.74 (0.54)	0.050	0.038
Distillate Oil	0.18 (0.63)	0.36 (0.43)	0.74 (0.54)	0.050	0.038
Gas	0.031 (0.63)	0.0011 --	0.31 (0.45)	0.029	0.0052
Residential					
Coal	1.8	8.6	0.45	0.76	0.23
Residual Oil	--	--	--	--	--
Distillate Oil	0.13	0.36	0.05	0.063	0.038
Gas	0.032	0.0010	0.018	0.036	0.014

Uncontrolled and controlled emissions from commercial, industrial, and residential heating sources have been estimated on the basis that all commercial boilers will be fired by natural gas or low-sulfur fuel oil by 1975.

	Emissions, Uncontrolled, all Fuels, millions metric tons/yr				
	Particulates	Sulfur Oxides	Nitrogen Oxides	Carbon Monoxide	Hydrocarbons
Commercial					
1971	.15	.57	.50	.005	.03
1975	.20	.99	.59	.005	.03
1979	.23	1.49	.68	.005	.04
Industrial					
1971	7.73	4.8	1.3	.84	.07
1975	8.3	6.7	1.5	1.1	.08
1979	10.3	8.8	1.8	1.3	.09
Residential					
1971	.09	.3	.05	.07	.02
1975	.09	.3	.05	.07	.02
1979	.09	.3	.05	.07	.02
	Emissions, Controlled, all Fuels, millions metric tons/yr				
Commercial					
1975	0.20	.99	--	--	--
1979	.23	1.49	--	--	--
Industrial					
1975	.62	4.9	1.4	--	--
1979	.79	6.1	1.6	--	--

Control Technology

It is apparent that equipment fired with gas and distillate oil burning meets essentially all of the air pollution regulations. The most cost-effective control technology has been switching from coal and high-sulfur residual oil to the less-polluting fuels. The current shortages and projected price rises for natural gas and distillate oils, and the proposed ban on switching to these fuels, fuel switching (to gas and distillate oil) will require implementation of other control technologies.

Estimates of control costs are based on the assumption that for commercial boilers, fuel switching from coal and high-sulfur residual oil to low-sulfur residual oil is attainable, and that for industrial boilers, fuel switching from high-sulfur residual oil to low-sulfur residual oil is attainable. Alternative control technologies for coal-fired industrial boilers include double alkaline scrubbers for sulfur oxides control in series with scrubbers or electrostatic precipitators for particulates control. For the coal-fired boilers, flue gas treatment appears plausible for the larger units, while fuel switching appears realistic for the smaller ones. However, because no boiler size distribution was available at this time, all industrial coal-fired boilers were assumed to utilize flue gas treatment as the control technology. This assumption is basically a conservative one.

Because of the present instability and future uncertainty of fuel prices, no attempt was made to account for the cost differential among fuels. On a Btu or heating valve basis, there could be little difference in costs. Although it appears that the cost of coal and high-sulfur residual oil would be lower than the cost of the clean fuels prior to firing in a boiler, the higher costs of handling the coal and high-sulfur residual oil as well as the higher equipment maintenance costs, are judged to offset any price differential. The net effect of these kinds of considerations would produce virtually equivalent fuel costs on a consistent basis.

Control Costs. The estimated control costs for three model heating plants are given in Table V- 1. Investments and annualized costs are considerably lower for commercial than industrial installations because of the relative ease of fuel switching compared to the use of sophisticated flue-gas cleanup systems.

The estimated total direct control costs for commercial, industrial, and residential heating for the period FY 1971 through FY 1975 are as follows:

	$ Millions		
	Expected	Minimum	Maximum
Existing Facilities			
Investment	4140	2610	5360
Annual Costs			
Capital Charges	570	355	744
Operating and Maintenance	527	61	961
Total Annual Costs	1097	416	1695
Cash Requirements	7450	4850	9630
New Facilities			
Investment	1400	820	1820
Annual Costs			
Capital Charges	207	131	261
Operating and Maintenance	189	116	248
Total Annual Costs	396	247	509
Cash Requirements	3130	1690	4100

TABLE V-I. COSTS OF CONTROL FOR THE MODEL PLANTS COMMERCIAL AND INDUSTRIAL HEATING SYSTEMS

Model Size, 1000 kg cal/hr	Investment, $1000			Annualized Cost, $1000			Unit Cost, 1000 kg cal/hr		
	expected	min	max	expected	min	max	expected	min	max
Commercial Heating (Sulfur Oxides and Particulates)									
315	25.2	17.9	31.7	6.4	-0.6	11.8	20.3	-1.90	37.4
Industrial Heating (Sulfur Oxides only)									
4250	498	292	658	147	86.5	195	34.6	20.4	45.9
Industrial Heating (Particulates only)									
4250	179	109	250	45.5	23.8	69.2	10.7	5.60	16.3

VI. BENEFITS OF AIR POLLUTION CONTROL

INTRODUCTION

The costs of air pollution control (abatement costs) are incurred as a result of efforts to reduce existing levels of pollution or to prevent what would otherwise be an increase in the pollution level. These abatement costs are incurred to reduce the pollution costs imposed upon society. Pollution costs include damage costs, avoidance costs, and psychic costs.

The benefits of pollution control are the reductions and prevented increases in psychic, damage and avoidance costs. The desire to obtain these benefits has led to establishment of laws, programs and policies designed to control air pollution and improve air quality. These programs and policies result in abatement costs and economic impacts to society, and the major focus of this report is to examine these abatement costs. Although some assumptions are needed and there are data problems, it is possible to estimate the major abatement costs involved. However, it is not as easy to estimate the benefits (reduced pollution costs).

POLLUTION COSTS

Psychic Costs

The psychic costs imposed by pollution are distinguished from damage and avoidance costs in that no out-of-pocket expenses are involved. People simply tolerate or live with these costs. These costs include the following: (1) the mental discomfort or anguish persons feel because they perceive air pollution becoming worse and believe this threatens to destroy human life; (2) the mental discomfort persons feel because loved ones are ill more often or more acutely or die prematurely; (3) the discomfort resulting from direct exposure to the pollutants like smarting eyes, shortness of breath, physical weakness, etc. (If these effects result in additional health costs, reduced productivity, or increased accidents, in principle, they should be included in the pollution damage category discussed below); (4) the lost in pleasure because there is reduced sunlight, restricted visibility, increased discoloration of buildings, and damaged or discolored vegetation; and (5) the mental discomfort or anguish some persons feel because they believe nature is being assaulted and that there is inherent value in keeping things as near natural as possible.

Persons desire to reduce these psychic costs. The strength of that desire can in principle be measured as the amount people would be willing to pay to avoid the discomfort and anguish. In practice, it is very difficult to accurately measure this willingness to pay. To some extent, people reveal the strength of their desire to reduce psychic costs by the support they show for government programs and policies on air quality improvement. People adjust their support for these programs and policies because they realize that abatement is obtained at some expense in terms of increased taxes, a reduction in other services, or increased prices.

Damage Costs

Damage costs of pollution refers to those pollution effects that result in an out-of-pocket expense or loss in profits or income. These costs include: (1) reduced yield of horticultural, agricultural, and forest products and replacement of affected horticultural plants. (Since the effects of reduced yields may be to increase prices and thus profits for farmers, costs to society must be determined by the effects at the consumer level); (2) hospital, doctor, and medicine expenses; (3) reduced useful life of machinery, equipment, building and other materials; (4) reduced productivity of persons and materials; (5) extra expense needed to maintain a desired level of cleanliness (soiling costs); (6) value of days of activity (housework, school, employment, etc.) lost; and (7) reduced value of property.

Again, people desire to reduce these costs. In principle, their willingness to pay for the damage reductions should be equal to the value of the damages. Although there exist problems with data, particularly with accurately determined cause and effects relationships, estimates of the value of damages can be made for many of these kinds of damages.

Avoidance Costs

Avoidance costs are the costs incurred to reduce or avoid the potential damages from pollution. Both the damage and avoidance costs are generally out-of-pocket expenses. Pollution avoidance costs include the extra expenses involved in: (1) more frequent painting of materials subject to deterioration; (2) the purchase of horticultural plants resistent to pollution; (3) air conditioning; (4) the use of resistent materials; (5) movement to a new home, job, or both; (6) shifts in the location of agricultural crop production; and (7) traveling further for an acceptable recreation site.

Reducing these costs makes people better off because resources are released for other purposes. Some of these costs can be quantified and valued because the response (use of resistent materials) can be related directly to the pollution problem. For others, the action taken (moving to a new house or traveling further to a new recreation site) may be in response to many factors other than pollution. Determining the share that is attributable to pollution is difficult.

The fact that certain benefits have not been quantified or valued in economic terms does not mean that they are unimportant. Quite clearly, they can be very important. This importance is revealed by the fact that most of the goals stated by environmental groups deal with benefits that are typically not measured. Exactly how important these unmeasured benefits are, compared to benefits that have been quantified, is uncertain. In any decision analysis that involves comparing the costs of proposed actions with the expected benefits, all benefits, not just those that have been measured, must be considered.

A formal procedure for trading-off changes in costs or benefits to society and shifts in the distribution of costs and benefits does not exist. Such trade-off analysis is important and is currently done on a judgment basis, often in the political decision-making area.

The benefits of pollution abatement are obtained in two ways. One is to reduce the existing pollution level to the national ambient standards or some other target level. This additional control would reduce the level of pollution costs (psychic, damage, and avoidance costs). The second way is to prevent pollution levels from becoming worse. This is done to avoid additional pollution costs. In evaluating effectiveness of current or proposed programs, the abatement costs should be compared to the sum of the reduced pollution costs and avoided pollution costs.

Earlier a distinction was made between psychic, damage, and avoidance costs. These distinctions will aid in understanding the benefits of pollution control. However, when empirical estimates of pollution costs are made, it is not always possible to identify which categories of pollution costs are being measured. For example, property value estimates may include some of all three kinds of pollution costs.

METHODS OF ASSESSING AIR POLLUTION COSTS

What are the methods that can be used to measure society's willingness to pay for improved air quality? There are basically six methods that can be used. These methods are: (1) valuing physical (dose-response) relationships; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys; (5) political expressions of social choice; and (6) the delphi method. Each method has been used under different circumstances with varying degrees of success. These methods have attempted, in most cases, to measure the value of the pollution costs suffered by receptors because of air pollution.

The most widely used technique is to determine a physical (dose - response) relationship between a pollutant and an object or living thing. These relationships are determined by designed experiments or by analysis of many observations of natural events. The physical relationship is then transformed into economic terms by determining values for the effects. The aggregate or national damage estimate is obtained by determining the population exposed to various levels of the pollutant.

In many cases the magnitudes of these physical and biological damages can be predicted with some degree of accuracy because the forms of damage under restricted conditions are known. Attempts to translate these physical and biological damages into meaningful economic relationships, however, have been less successful in identifying economic damages over a range of pollution exposures. Success in this method has been obtained only within narrowly circumscribed limits.

In using the market study approach, air pollution damages are measured through the explicit use of market valuations. The consideration, here is the impact of air pollution dosages on human behavior as reflected in markets. This approach completely circumvents the need to know the physical or biological damage function--the basic dose-response relationship. The investigator applies statistical tools and economic models to isolate the incremental adverse effect of air pollution on a particular activity or behavior as expressed in the marketplace.

A specific application of the market study approach is the use of property values to estimate air pollution damages. Given that people are willing to pay to avoid the effects of air pollution, property values and air pollution concentrations must vary inversely. A significant problem in using the market study approach is that all the factors that explain consumer preferences and behavior must be included in the analysis. Such an explanation is, of course, a monumental task, both theoretically and empirically. Also, if market value estimates are added to other estimates, there is the possibility of counting an effect twice.

The third method, opinion survey of air pollution sufferers, is closest tothe classical economic approach in that it focuses on estimating utility and demand functions. Investigators employing this method have attempted to ascertain what people do and do not perceive as air pollution effect. If it can be assumed that people know explicitly the effects of air pollution, then the objective is to elicit complete information from them in a way that would dissuade untruthful responses.

In general, opinion surveys have shown particular usefulness in understanding how attitudes about air pollution are formed and then affected by changes in air quality, and what people do and do not perceive as air pollution effects. This method can also provide some insight into what people might be willing to pay for improvement in the air environment, or perhaps, what their demand might be for the reduced risk of experiencing certain adverse effects. However, values obtained by asking people directly what they would be willing to pay must be interpreted with care, as many factors, like lack of knowledge of other alternatives, affect their response.

Litigation surveys could be used to determine the extent to which people have turned to the courts for redress for air pollution damages. Because of the pervasiveness of air pollution, especially in urban areas, and because city dwellers become conditioned to air pollution, the use of this method is limited.

In utilizing the fifth method, political expressions of social choice, the investigator tries to gauge political expressions, representations, and exhortations in the hope that their intensity somehow corresponds to intensity of preference for one outcome over another.

In employing the delphi method, the knowledge and abilities of a diverse group of experts are pooled for the task of quantifying variables which are either intengible or shrouded in uncertainty. Essentially the method is one of subjective decision-making. The use of this method provides an efficient way to obtain best judgements from the knowledge and opinion of experts.

Of these six methods, valuing does-response relationships, and a particular market study application--the property value method--have yielded the most promising insights into the true nature of air pollution damages. Again, with effective abatement, these damages become the benefits of control. Yet, even the application of these methods has been fraught with many problems. Air pollution is but one environmental stress, and it is difficult to allocate the observed damages among a number of synergistically interacting multiple stresses; and the damages themselves cannot be easily measured and reduced to economic terms.

POLLUTION COST ESTIMATES

The benefit numbers contained in this report pertain, for the most part, to reducing pollution to meet the established or assumed ambient air quality standard and should only be compared to that increment of abatement costs incurred to reduce pollution to this level. In many cases, the costs reported in this report serve to reduce pollution substantially below this level, thus making the cost and benefit numbers uncomparable.

Specifically, the numbers are estimates of the reduction in some of the pollution costs that would result from reducing the 1970 level of certain air pollutants to meet the standars. Not all of the costs of even this change in pollution levels have been estimated. For example, the damages to animals and the natural environment have not been obtained. This does not imply that the latter pollution costs do not exist, but only that there is not enough information to make an estimate.

Table IV-1. NATIONAL ESTIMATES OF AIR POLLUTION COSTS, BY POLLUTANT AND EFFECT, 1970
($ billion)

Effects	Sulfur Oxides			Particulates			Oxidants[a]			Carbon Monoxide	Total		
	Low	High	Best	Low	High	Best	Low	High	Best	Best	Low	High	Best
Aesthetics & Soiling[b,c]	1.7	4.1	2.9	1.7	4.1	2.9	?	?	?	*	3.4	8.4	5.8
Human Health	0.7	3.1	1.9	0.9	4.5	2.7	?	?	?	?	1.6	7.6	4.6
Materials[c]	0.4	0.8	0.6	0.1	0.3	0.2	0.5	1.3	0.9	*	1.0	2.4	1.7
Vegetation	*	*	*	*	*	*	0.1	0.3	0.2	*	0.1	0.3	0.2
Animals	?	?	?	?	?	?	?	?	?	*	?	?	?
Natural Environment	?	?	?	?	?	?	?	?	?	?	?	?	?
Total	2.8	8.0	5.4	2.7	8.9	5.8	0.6	1.6	1.1	?	6.1	18.5	12.3

[a] Also measures losses attributable to oxides of nitrogen

[b] Property value estimator

[c] Adjusted to minimize double-counting

[?] Unknown

[*] Probably negligible

Sources: Waddell, Thomas E., "The Economic Damages of Air Pollution: Unpublished Report, EPA National Environmental Research Center, Research Triangle Park, March, 1974.

Estimates of the costs of some of these adverse effects are shown in Table VI-1. For each kind of effect and each pollutant, a "best" estimate and range are presented. The "best" estimate is the most likely true value. However, the range demonstrates that the most likely true value could be much larger or smaller than the "best" estimate. A wide range implies that little confidence can be placed on the "best" estimate, while a narrow range implies more confidence. The question mark is used to identify cells which are expected to have pollution costs, but for which data deficiencies preclude making an estimate.

The estimate of aesthetic and soiling costs was obtained from a study of property values. The property value estimate provided a measure of the psyhic costs, damage costs and avoidance (including adjustment) costs that people suffer because of sulfur oxides and particulates. There is an absence of data on how the effects of oxidants and carbon monoxide might be capitalized in property values. This value was obtained from original study values by adjustment to avoid the double counting of health and materials damage effects.

Estimates of the cost of air pollution effects on human health, ma materials, and vegetation have been developed by applications of the technical coefficients approach. The estimates for health costs measure the value of damages resulting from air pollution effects--reduced productivity because of ill health or premature death and out-of-pocket health care expenses. Data concerning the effects of oxidants (hydrocarbons and oxides of nitrogen primarily) and carbon monoxide did not allow for the estimation of the value of damages by these pollutants. Psychic and avoidance costs are also omitted from these health estimates.

The materials estimates measure the value of damages and some of the avoidance costs resulting from air pollution damage to man-made materials. It is impossible to say what portion of avoidance costs are accounted for. Estimates of the value of air pollution effects on plants mostly represent the direct damages and generally ignore the avoidance costs and psychic costs.

The damage to anumals caused by air pollution has generally been localized, and its economic consequences have probably been relatively unimportant. Though indirect, the risk to the food cycle, especially when heavy metals or toxic substances are implicated, could be serious; and it may be true that the economic importance of many air pollutants may lie in their impact on animal populations. In general, little is known about the effects of air pollutants on domestic animals and wildlife. Also, little is known about how these problems interface with the natural environment.

The natural environment category includes the pollution costs or disruption or destruction of ecological systems, the destruction of species, the disruption of social systems or social patterns, and the disruption of a man-nature balance. Many of these pollution costs affect man as psychic cost, particularly fear of man's inadvertently destroying life on earth. Because they are mostly psychic costs, there is great difficulty in quantifying them, and no estimates are yet available.

AESTHETICS AND SOILING

The aesthetic effects of air pollution represent a category which is very difficult to describe. In general, man wants an environment congenial to his aesthetic and psychological needs. Yet air pollution restrains progress toward such an environment. Odors from various sources deprive many of the full enjoyment of their property. Suspended particulate matter can diminish visibility, obscure vistas and restrict normal travel. Oxides of sulfur accelerate the decay of works of art and statuary. Emissions from automotive combustion and their resultant atmospheric interactions injure ornamental planting, often cause watering of the eyes, and can have a depressing psychological effect, thereby diminishing the quality of life.

Soiling affects individuals, households, and commercial establishments in many ways, only a few of which are obvious. When dust particles collect, the need to clean window sills, floors, walls, carpets, draperies, and furniture is distressingly obvious. But the effects of air pollution in most cases are so much more gradual as to be unnoticed. Some of these subtle costs are associated with the following: cleaning and maintenance of homes, commercial and public buildings; individual adjustments such as laudering, and car washing.

It is hypothesized here that many of the psychic and avoidance costs associated with soiling and the detrimental effect of air pollution on aesthetic properties, are capitalized in property values. Thus, tests of the relationship between property values and air quality should provide some insight into the magnitude of these costs. But at the same time, many significant aesthetic and soiling-related costs are probably not capitalized in the property market, and thus are not measured.

A number of studies have convincingly shown that differentials in property values with respect to air quality levels exist in the housing market. The basic hypothesis of property value studies is: if the land market were to work perfectly, the price of a plot of land would equal the sum of the present discounted stream of benefits and costs derivable from it; and, since air pollution is specific to locations and the supply of locations is fixed, there is little likelihood that the negative effects of pollution can be significantly shifted onto other markets. Therefore, it is to be expected that many effects are reflected in this market, and that these effects can be measured by observing associated changes in property values.

Several property value studies have been performed in urban areas and have attempted to explain the relationship between property values, air quality, location, heighborhood factors, occupant characteristics, and physical property characteristics. Data measurements were obtained from cross-sectional samples over either individual properties or aggregates of properties such as census tracts. These studies revealed a statistically significant inverse relationship between air pollution and property values or rent. The air quality parameter studied was for sulfation, suspended particulates, sulfur dioxide, and dustfall. Sulfation was used most often. The value of the marginal property value differential ranged from about $100 to $750 per residence.

To estimate total damage costs using the property value technique, one would have to perform separate property value studies for residential, commercial, industrial, and agricultural land. Given the paucity of information in areas other than residential, total damage estimates are made only for those damages capitalized in the residential property market and measured through site differential values. The uniformity of results, for six major metropolitan areas, warrants confidence in the housing market estimator as a measure of some of the aesthetic and soiling costs from air pollution.

The national estimate for 1970 of air pollution damages measured via the property value method, comes to $3.4-$8.2 billion. A "best" approximation would probably be a middle estimate for a marginal property value of $350, or a total damage of $5.8 billion.

It is believed that the costs associated with aesthetic effects as well as soiling-caused cleaning and maintenance expenditures are capitalized in this estimator. These effects are the tangible, experimental aspects of air pollution: more rapid deterioration and extra cleaning and maintenance costs, the milder medical symptoms, such as shortness of breath and smarting eyes, plus smells and dirt. Here the $5.8 billion is used as an estimate of the damages to aesthetic properties and soiling, although it is recognized that other effects may be included in the estimate.

HEALTH

Of the benefits that result from the abatement of air pollution, those to human health rank with highest priority, particularly in the short run. If health is defined as a general state of well-being, then a health benefit is some improvement in one's general well-being or welfare. In an economic sense, we want to determine, if possible, the value of that improvement. Such improvement might be in: lower illness and death rates, including partial disability; fewer absences from work, school and other normal activities; and/or, a reduction in general expenditures on health protection and care

The traditional method of valuing human health has been to sum the loss of output and the cost of medical care. For morbidity, this is the approach that determines the value of out-of-pocket expenses, and the value of work days lost--a measure of lost productivity--or, more generally, the value of restricted activity days. In the case of mortality, this approach determines the present value of lost future earnings due to premature death. A major limitation of the lost productivity approach is that the "worth" of those who do not produce--retirees, students, housewives, etc.--is often counted as zero. It is believed that the approach that measures only lost output and out-of-pocket medical costs, ignores a number of personal and social valuations that could be quite significant. Because of these omissions, the values presented are a lower bound of the value of health benefits. The discussion of the estimation of human health benefits will fall into two categories--mortality and morbidity.

A general method used in investigating the mortality-air pollution relationship is multi-variate regression. Cross-section studies have shown that variation in mortality can be explained, in part, by air pollution (suspended particulates and sulfation in this case), population density, race and age. Estimates from one linear relationship between air pollution and mortality show that a 50 percent decrease in air pollution would be associated with a reduction in the mortality rate of 4.5 percent. By applying this factor of 4.5 percent to the cost of mortality, one can estimate the value of the health benefits for increased life expectancy by reducing air pollution.

In estimating morbidity costs, one encounters many of the same problems as those encountered in studying mortality. Again, the investigator must consider a host of parameters if he is to isolate the incremental effect of air pollution on hyman health and avoid developing spurious relationships.

A recent study from EPA's Community Health and Environmental Surveillance Studies (CHESS) Program affords the opportunity to estimate the morbidity cost of selected adverse health effects associated with the pollution composite, sulfur dioxide-total suspended particulates-suspended sulfates. Data from the CHESS program were collected from a number of CHESS communities offering different pollution gradients. These communities were specifically selected to control for major co-determinants that might affect disease rates.

Measurements on health and socio-economic characteristics, meteorology, and environmental pollutant exposure measurements were taken in CHESS on tens of thousands of individuals to estimate the relative effects of multiple pollutant exposures. The health effects investigated were: irritation symptoms arising from acute air pollution episodes; impairment of ventilatory function; sumptom aggravation in the elderly, asthma attacks; acute lower respiratory illnesses; and chronic bronchitis.

By extrapolating these findings from CHESS, it is believed that air pollution-related morbidity costs for selected health effects can be estimated. The following information is used to make an extrapoltation. The first, specific health effects are identified in different reports from CHESS. Second, estimates of affected populations are based on: an internal EPA report on populations-at-risk; data on disease rates published by the National Center for Health Statistics; and population data from the Bureau of Census. Third, the estimated change for each health effect is based on an interpretation of the data reported in the individual CHESS studies. and Fourth, estimates of cost-per-health effect are based on information taken from the Statistical Abstract of the U.S. for 1972 and reports from the National Center for Health Statistics, tempered with best judgment. Results of this process yield rough estimates of the benefits to human health of controlling sulfur dioxide, suspended particulates, and suspended sulfates. The human morbidity costs for 1970 determined in this manner are estimated to range from roughly \$.9 to \$3.2 billion.

In extrapolating the mortality regression results, if 1970 air pollution levels (total suspended particulates) were reduced by 26% (in order to reach the primary ambient air quality standard), the savings in mortality and non-respiratory morbidity costs would be \$3.51 billion. This estimate is reduced to \$2.58 billion to adjust for the fact that 26.5% of the population do not live in urban areas. Adjusting by the variance about the mean, a range of \$0.7-4.4 billion is generated for 1970. Adding this range to the range of \$.9-3.2 billion generated by extrapolating the CHESS data, the range of gross estimates of health costs associated with air pollution for 1970 becomes \$1.6-7.6 billion. This gross health estimate represents the benefits that would be realized by reducing air pollution in major urban areas to the particulate primary standard of 75 ug/m3, the sulfur dioxide primary standard of 80 ug/m3, and reducing sulfates to 6-8 ug/m3. It is concluded that the middle of the range, \$4.6 billion is the "best" estimate of the true costs of the adverse effects of the pollutant complex considered, on human health and longevity.

MATERIALS

Air pollution has a variety of effects on materials--the corrosion of metals, the deterioration of materials and paints, and the fading of dyes. There have been a number of attempts at estimating the resultant economic losses due to the detrimental effects of air pollution. These losses represent premature replacement costs and preventive and maintenance costs.

Studies of the economic effects of air pollution on materials seek to: (1) identify the materials, air pollutants, and environmental factors that should be studied in order to assess the economic damage to materials caused by air pollution; (2) analyze systematically the physical and chemical interactions among the variables identified for the purpose of determining cause-effect relationships; (3) determine, where possible, the pollutant dose-response relationship for materials that are significant because of their relative economic value and to indicate how this may be done where such relationships are presently defined; and (4) translate the pollutant and dose-response relationship into a pollutant and dose-cost-damage function.

The economic value of material exposed to air pollution is determined from annual production values, a labor factor to adjust for installation costs, an estimate of the life of the material, and an estimate of the percent of the material that is exposed to air pollution. The rate of economic loss was calculated as the product of the economic value of material exposed to air pollution times a value of interaction (the difference between the rate of material deterioration in a polluted environment compared to that in an unpolluted environment). The interaction value is expressed as dollars lost per year. The results of the operations described yielded an estimate of air pollution damages to materials of $3.8 billion.

A study of the effects of air pollution on rubber products estimated the yearly cost of this pollution at $475 million. Costs were measured as: (1) the increased costs at the manufacturer's level to provide products that are resistent to atmospheric pollutants (these are normally passed on to the consumer); and (2) the direct costs to the consumer in the form of shortened useful life of the product. The combined costs at the consumer level are used in estimating the total cost of pollution.

Recent work on the deterioration of exterior paints by particulate matter (primarily) and the interaction of particulate matter and sulfur oxides resulted in an estimate of the potential economic loss to manufacturers and consumers because of this deterioration at $704 million.

Information on human population distributions, coupled with sulfur dioxide data for about 150 Standard Metropolitan Statistical Areas for the years 1968-1972, provided a basis for estimating materials at risk to damage from sulfur oxides. Measures of the average annual relative humidity by SMSA were integrated into the analysis. This consideration is important because the corrosion damage function shows relative humidity to be more important than sulfur dioxide in causing corrosion. Using best availalbe damage function data for corrosion and paint deterioration, the estimate for 1970, SOx damage (where sulfur dioxide acts as a surrogate for all damaging sulfur compounds in the atmosphere) to metals and paints was approximately $0.4 billion. An analysis of available dose-response data on the effect of

SOx on susceptible materials concludes that SOx effects on textiles, building materials, leather and paper products, and dye-fading are probably negligible from an economic standpoint. A study of the economic effects of air pollution on textile fibers and dyes estimated damages at approximately $0.2 billion annually. The costs of fading of dyes in fabrics by oxides of nitrogen and ozone generally are based on: the increased cost of dyes more resistant to fading; the cost of inhibitors for cheaper dyes; the cost of research; the cost of quality control related to the use of more expensive dyes; and the costs to consumers and sellers with respect to any reduction in product life.

These studies provide the basis for a gross national estimate of air pollution damages to man-made materials. With adjustment for values obtained in the individual studies to avoid double counting, a total gross damage estimate for 1970 of $1.7 billion is obtained. A range of $1.0-2.4 billion is generated by assuming the same variance for materials as was determined for property values. Given the nature of the studies reviewed, this estimate should be taken as indicative of the general magnitude of damage in 1970 and not as the "true" cost of material damage.

VEGETATION

Damage to vegetation as a result of air contamination has been recorded in the United States since the turn of the century. What was once a problem associated only with point sources has evolved into an air pollution problem more commonly associated with urban expansion. The continued commercial and noncommercial production of crops and forests in many areas has been jeopardized and in some locations discontinued. A major study was undertaken to develop an estimate of the annual economic losses to agriculture in all regions of the United States resulting from damage to vegetation by air pollutants. The method was: First, counties were selected in the U.S. where the major air pollutants--oxidants (ozone, PAN, and oxides of nitrogen), sulfur dioxide, and fluorides--were likely to reach plant-damaging concentrations. This selection was based on fuel consumption and the existence of large single-source emitters. Second, the relative potential severity classes of the pollution in each county were then estimated, based on emissions area, and potential pollution episode days. Third, crop value estimates were completed for these counties. Fourth, estimates of the potential annual value of forests and the annual maintenance costs of ornamental plantings were completed and apportioned by area and population. Fifth, a continuing literature review provided information on the relative sensitivity of different plant species to the selected pollutants, so the percentage loss that might be expected to crops and ornamental plantings in the most severely polluted counties could be determined. Sixth, tables were then prepared showing the percentage loss that might be expected to crops and ornamentals in counties in the different pollution classes described in the second step above. And seventh, these factors were then applied to value of the crops, forests, and ornamentals grown in the polluted counties, and the dollar loss value for each crop in each county was recorded. From this, state, regional, and national estimates were obtained.

When the loss factors for the various pollution intensities in the 551 selected counties were applied to the determined crop and ornamental values, the total annual dollar loss to crops and ornamentals in the United States for 1970 is calculated to be about $0.2 billion. Assuming a variance of 50 percent, a range of $0.1-0.3 billion for 1970 is obtained.

COMPARING COST AND BENEFIT VALUES

It is desirable for any control program, policy or action that the benefits of reduced pollution costs be greater than the abatement costs; otherwise society will be made worse off by the action. In principle, it is easy to make this comparison. In fact, it is very difficult to obtain accurate enough cost and benefit values for a given program, policy or action to make a correct determination of the value of the action to society.

In particular, the values in this report, while providing some feel for the general validity of current programs, do not provide an adequate basis for accurate comparison of the cost and benefit of the entire program nor any particular part of the program.

One major problem is that not all of the benefits have been measured. Some judgmental value has to be assigned to the unmeasured benefits before the numbers would be comparable to abatement cost estimates. A second problem is that the values presented are national aggregates. A benefit-cost comparison of national costs and benefits would not indicate the merit of pollution control programs for individual regions of the country or for individual pollutants. Hence, the numbers presented here should not be used to judge the value of any particular environmental decision unless all the costs and benefits pertinent to that decision have been counted. The current state of the art of benefit assessment does not allow such comparisons in most cases.

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